Search for VLQs decaying to light SM quarks in Run 2 data from the ATLAS Experiment

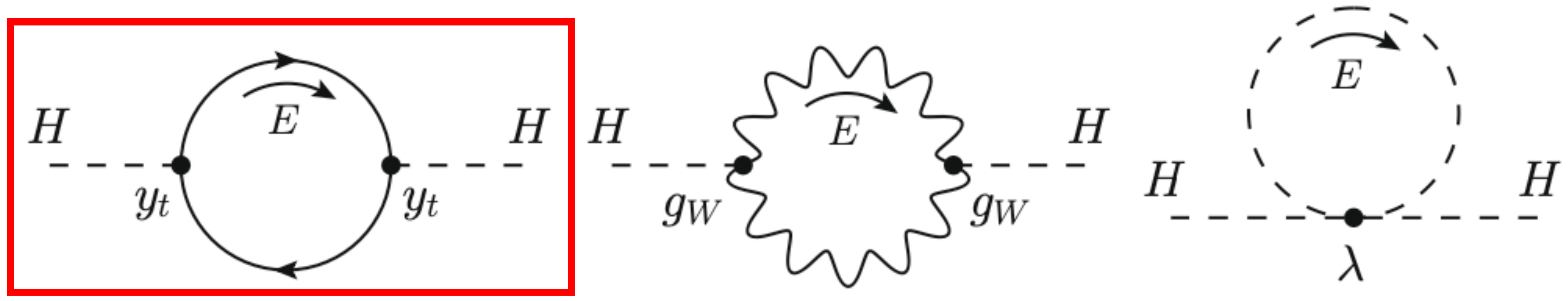
Zackary Alegria
Oklahoma State University

US LUA Annual Meeting, Fermilab

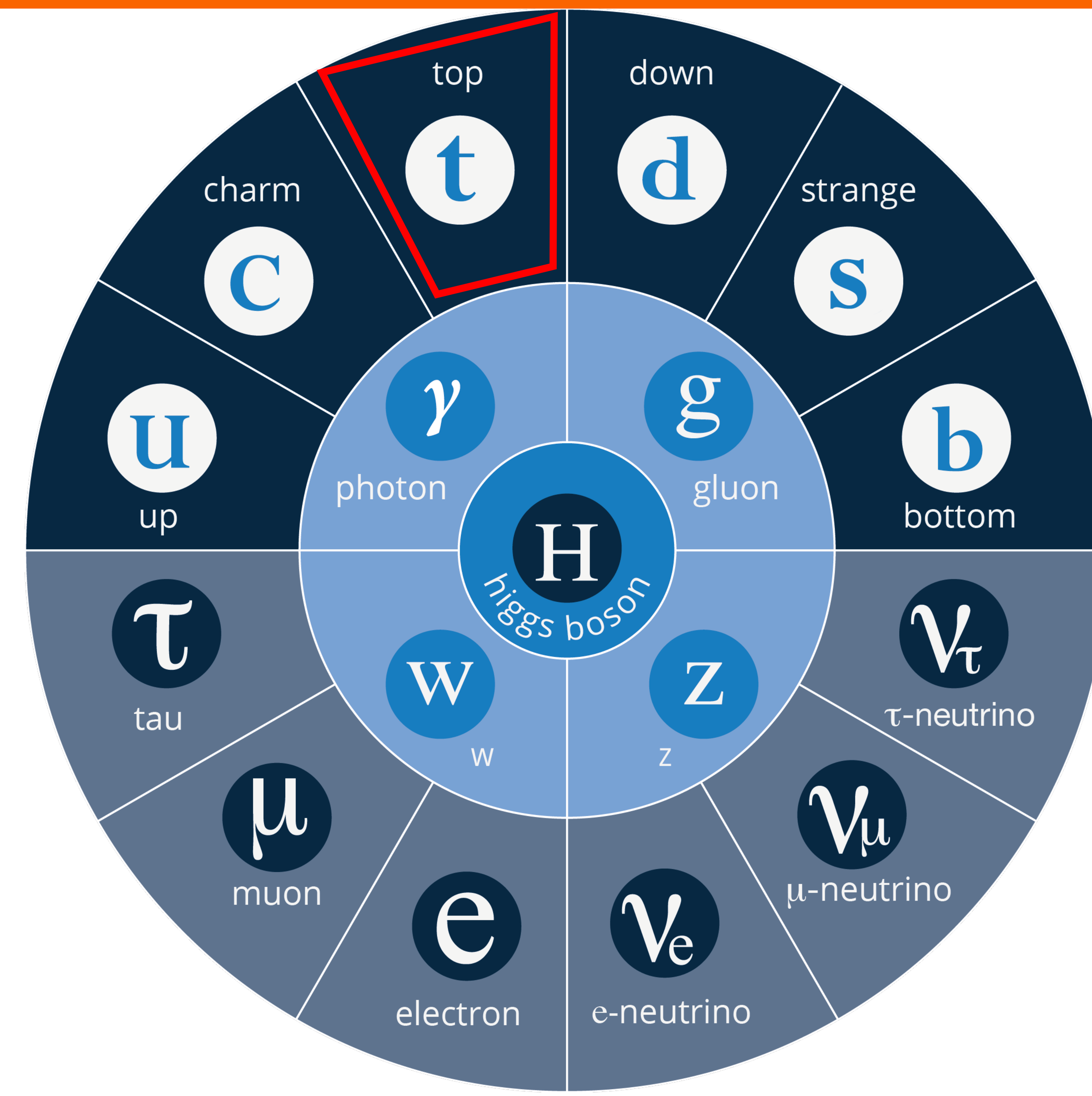
December 15, 2023

SM shortcomings as a motivation for new physics

- While successful in many aspects the SM is known to fall short of describing observable phenomena i.e. strong CP problem, dark matter, the hierarchy problem, etc.



From *The composite Nambu-Goldstone Higgs* by G. Panico and A. Wulzer



- Top quark dominant contribution to the loop diagrams ⇒ quadratic divergence
  - Introduce new heavy quark partner ⇒ cancel divergence

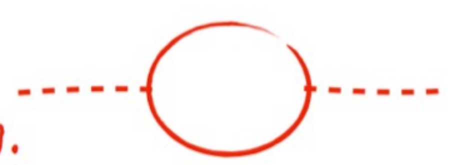
"bare mass"

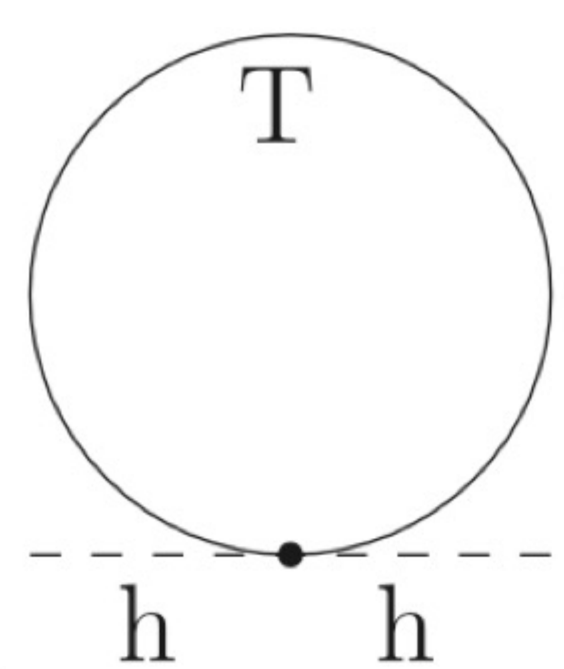
$M_H^2 = 3.27345942963429054386749647321596\,43$

$-3.27345942963429054386749647321596\,45$

$= 10^{-32}$ (in planck units)

quantum corrections, e.g.



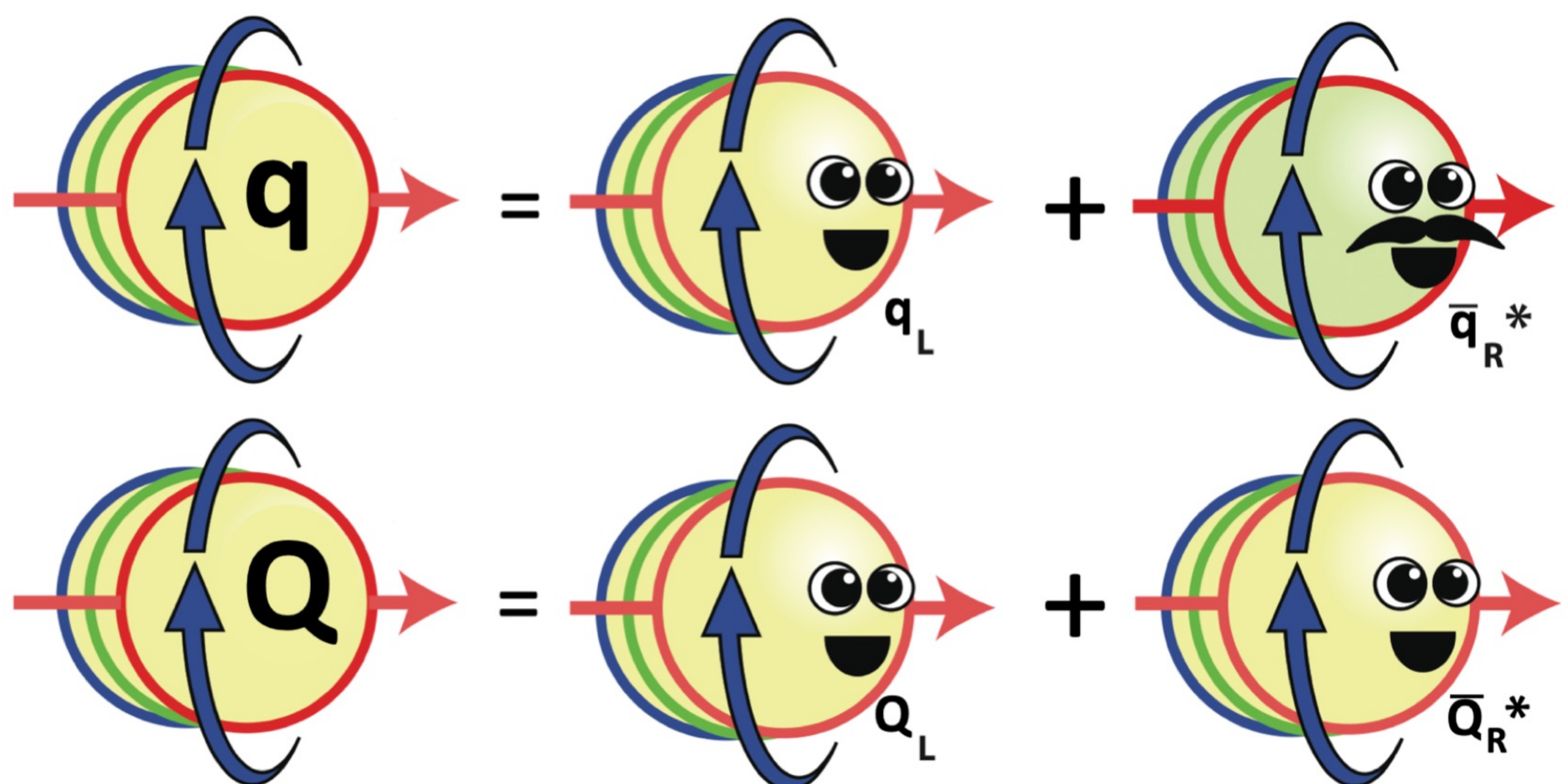


$M_H^2 \sim 10 - 9 = 1$ (in units of ~100 GeV squared)

from Roni Harnick and arxiv:1205.0013

What are VLQs?

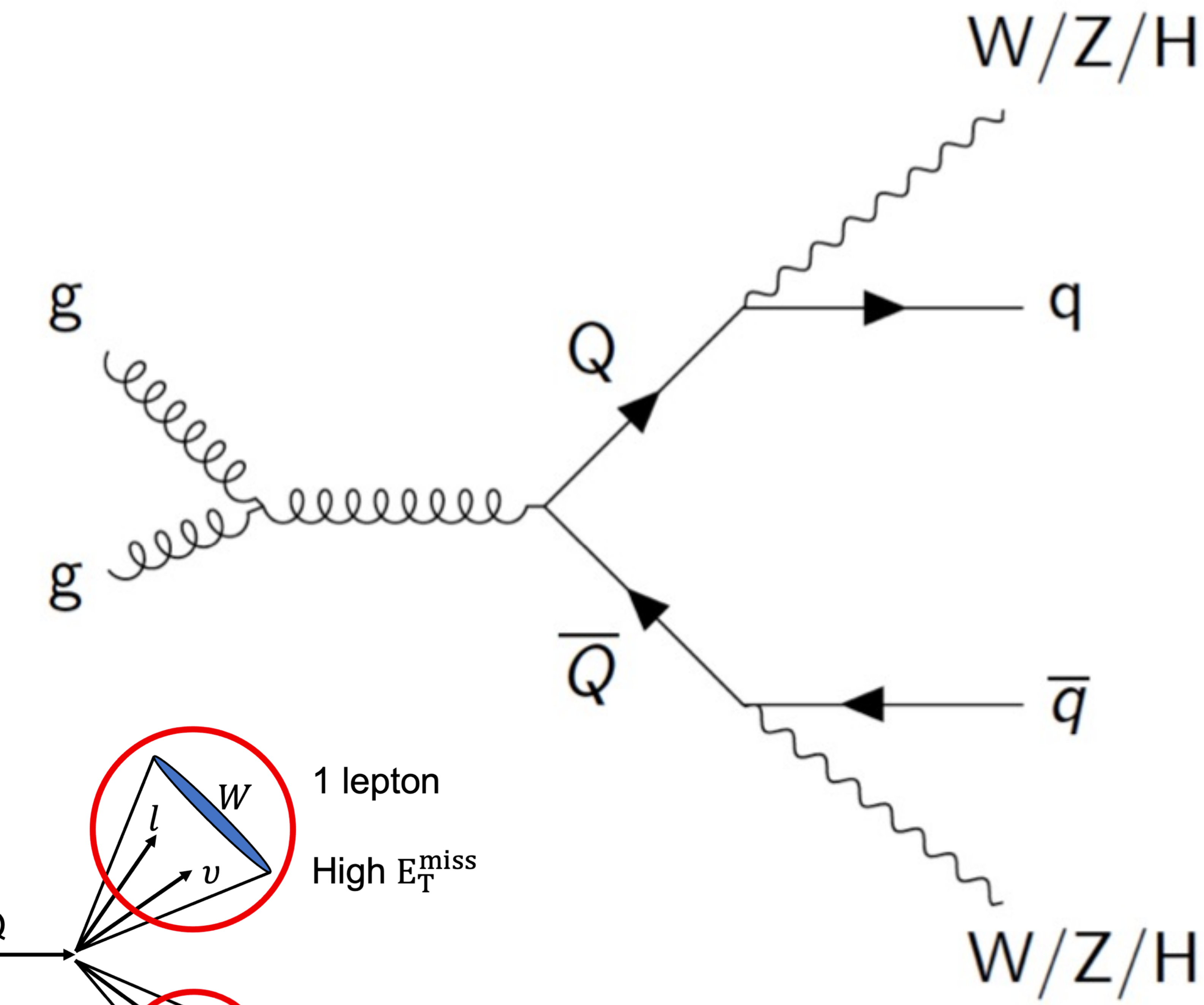
- Color charged spin ½ particles whose left- and right-handed components transform the same under $SU(2)\times U(1)$

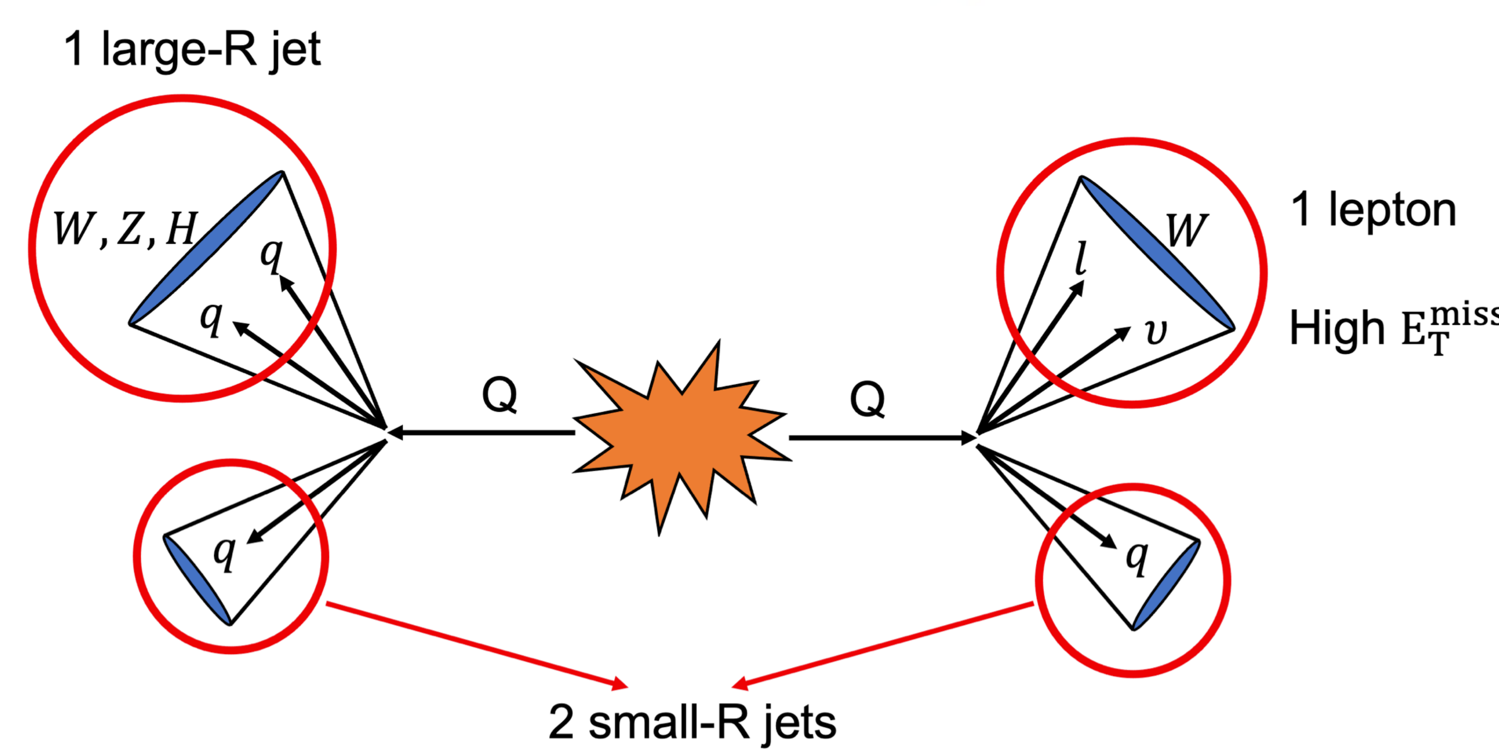


- Mass is not obtained from the Higgs boson
- Decays to a SM boson (H/W/Z) and quark

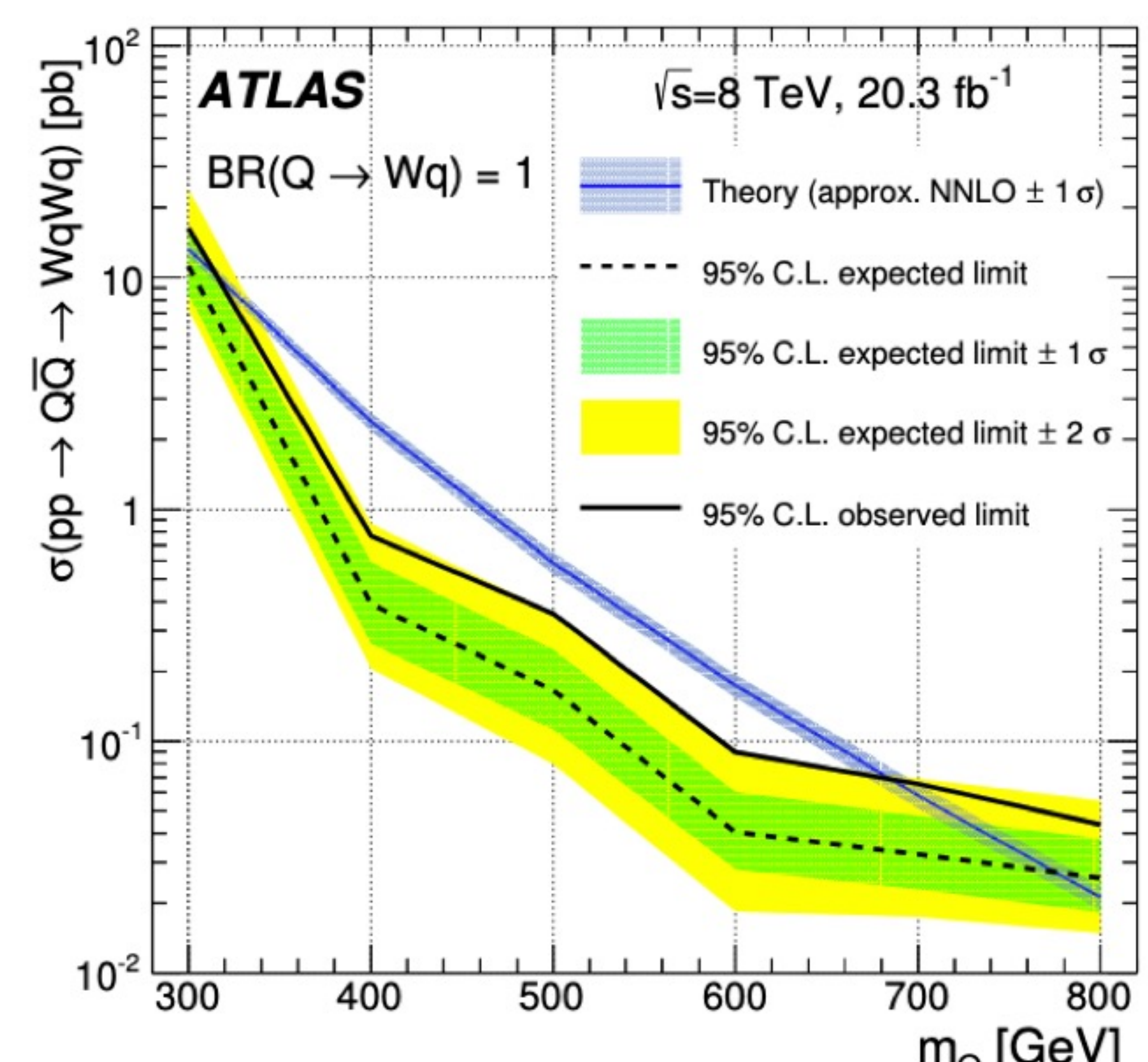
Wq+X Search

- Search for pair produced VLQs in the Wq+X final state assuming $\mathcal{B}(Q \to Wq) = 1$
  - Pair production provides model-agnostic lens
- Require: $Q \to Wq \to \ell\nu q$
- Optimize: $Q \to Wq \to q'q''q$





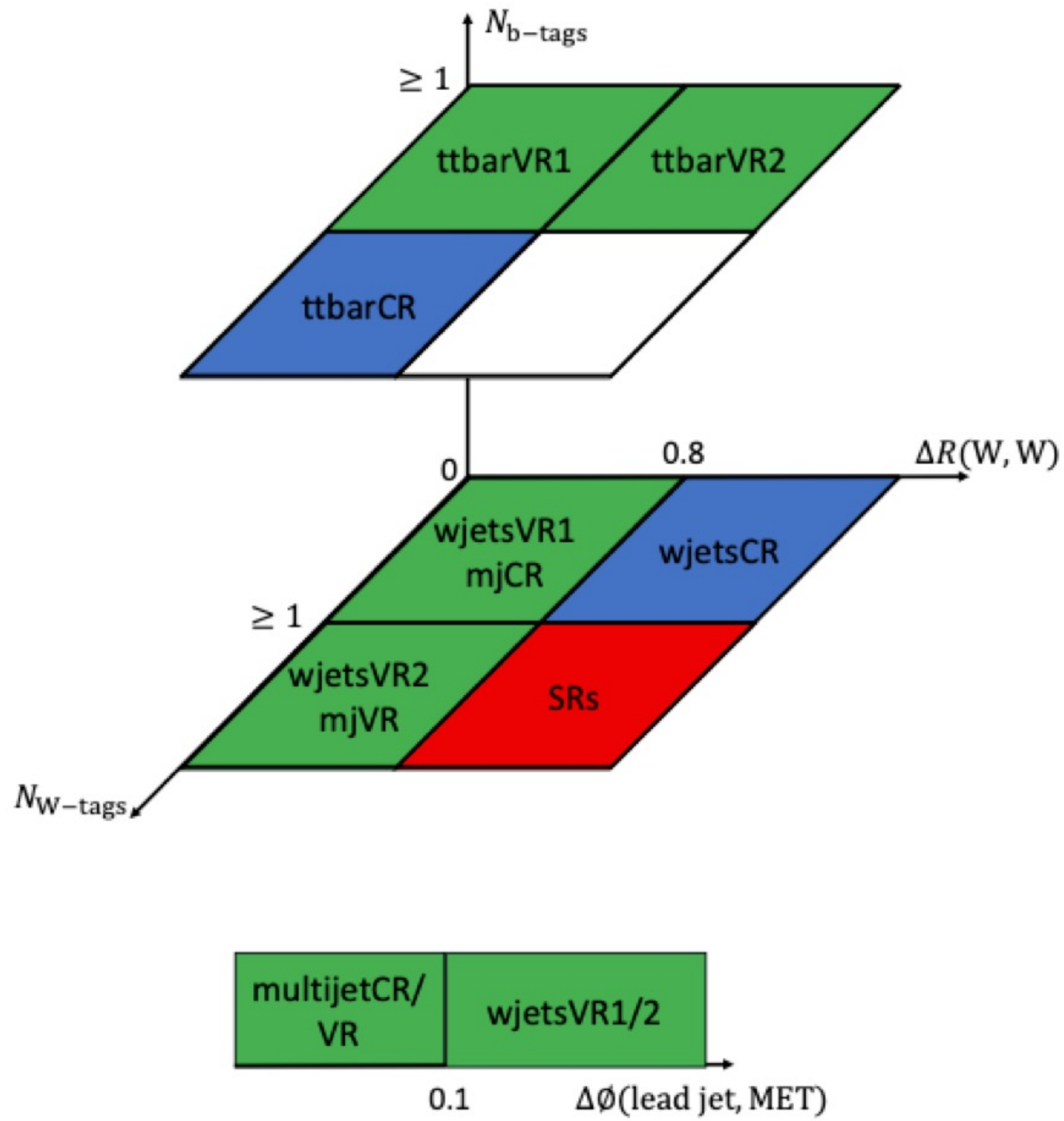
- Background contributions: W + jets (dominant), $t\bar{t}$, single top, multijet, Z + jets, diboson, ttV, and VH
- Run 1 analysis mass limit set at ~700 GeV
  - Expect to double this using full Run 2 data



Phys. Rev. D 92, 112007(2015)

Region Definitions

- After applying preselection cuts define the following regions
- 3 Control Regions
  - Multijet CR
  - $t\bar{t}$ CR ($t\bar{t}$ + singletop)
  - W + jets CR
- 5 Validation Regions
  - 1 Multijet VR
  - 2 $t\bar{t}$ VR
    - VR1 checks N_{W-tag} dependence
    - VR2 checks $\Delta R(W_{lep}, W_{had})$ dependence
  - 2 W + jets
    - VR1 checks $\Delta R(W_{lep}, W_{had})$ dependence
    - VR2 checks N_{W-tag} dependence
- 2 Signal Regions



Analysis Strategy

- 1. Reconstruct VLQ candidates

VLQ Reconstruction Strategy

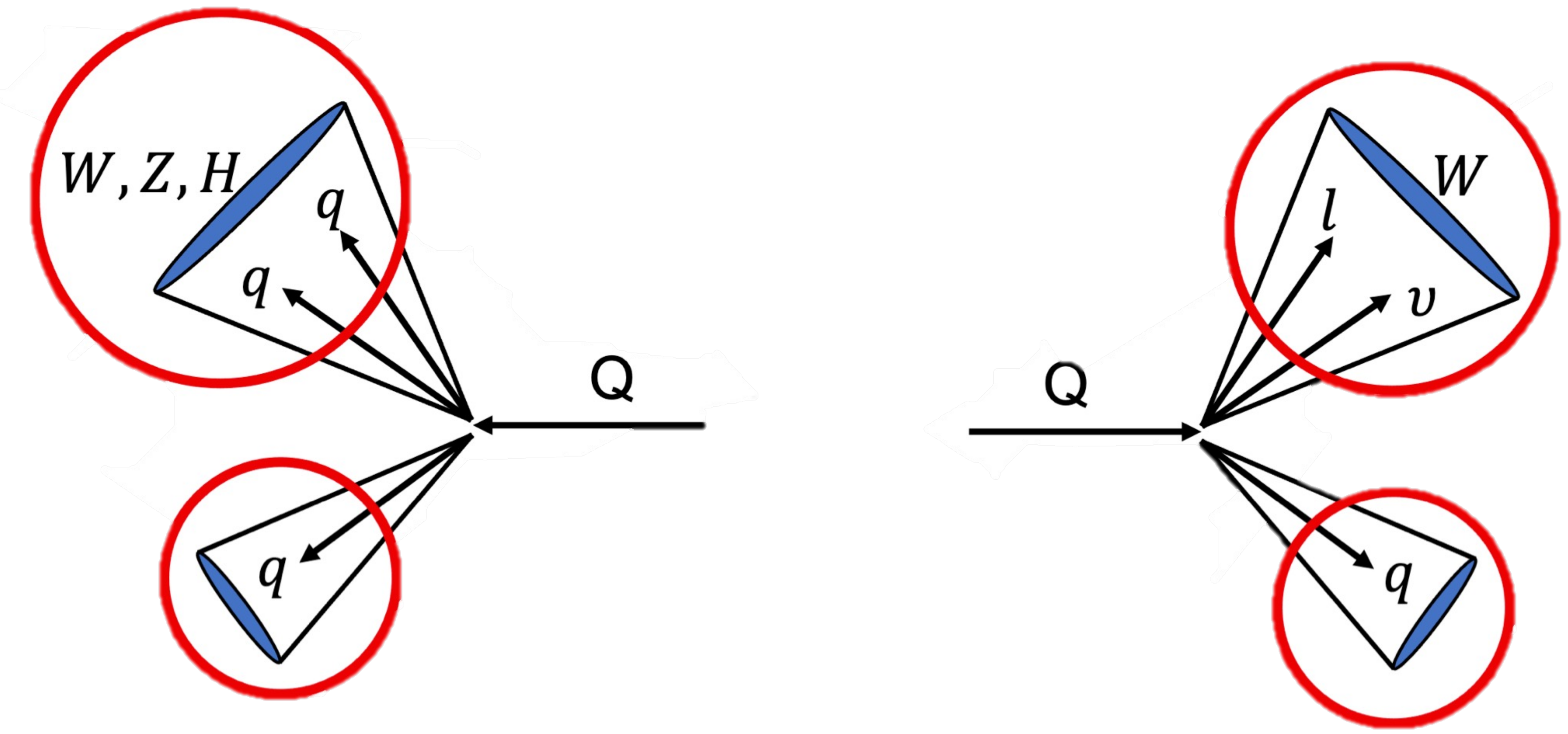
- Reconstruct neutrino
  - Calculate p_Z^{ν}
  - Use W boson mass as a constraint

VLQ Reconstruction Strategy

- Reconstruct neutrino
  - Calculate p_Z^{ν}
  - Use W boson mass as a constraint
- Reconstruct W bosons
  - Leptonic W: lepton + reconstructed neutrino
  - Hadronic W: leading W-tagged large-R jet
    - No W-tag ⇒ large-R jet mass closest to W mass

VLQ Reconstruction Strategy

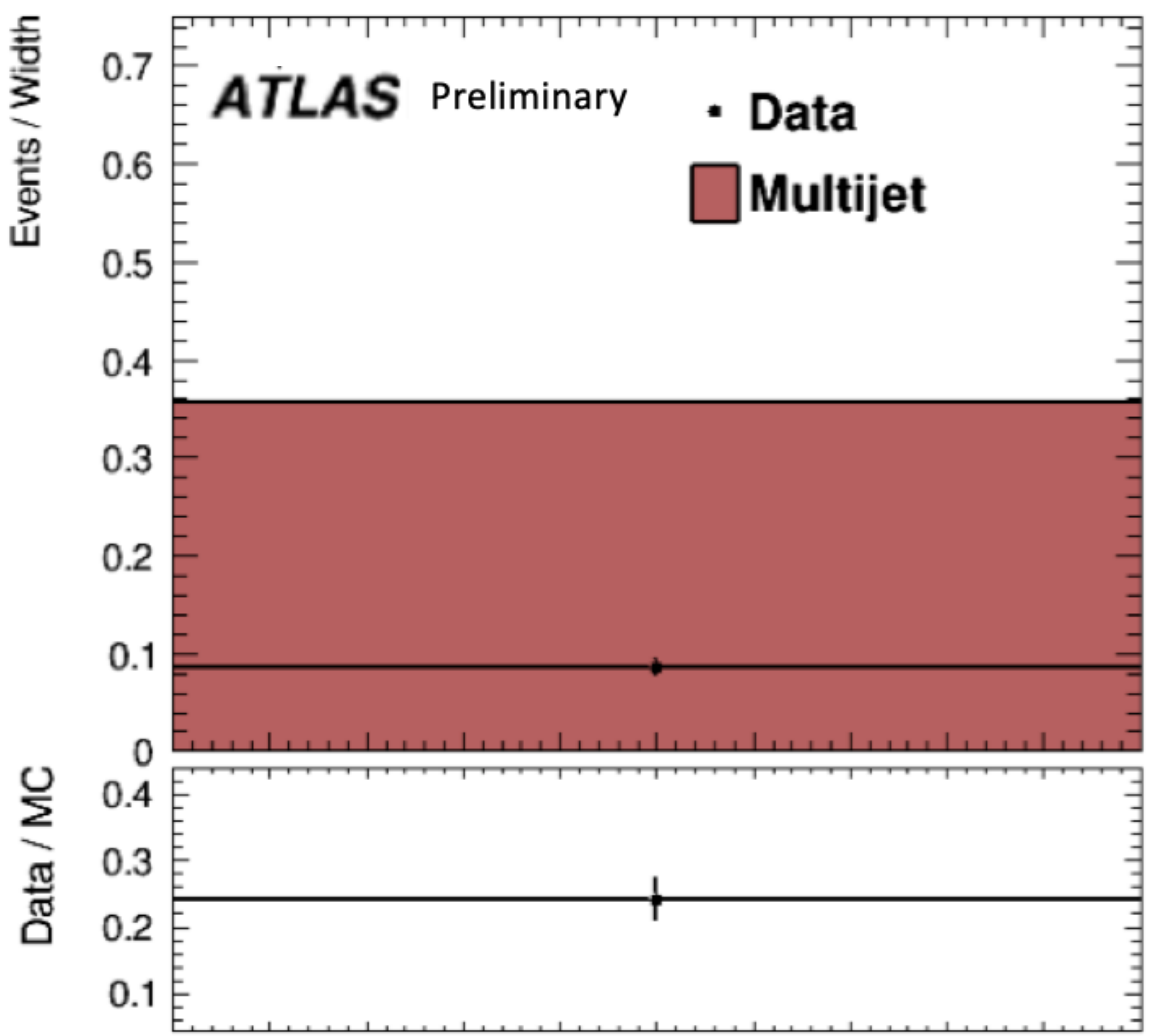
- Reconstruct neutrino
  - Calculate p_Z^{ν}
  - Use W boson mass as a constraint
- Reconstruct W bosons
  - Leptonic W: lepton + reconstructed neutrino
  - Hadronic W: leading W-tagged large-R jet
    - No W-tag $\Rightarrow$ large-R jet mass closest to W mass
- Reconstruct VLQ candidates
  - Use leading 3 small-R jets to reconstruct VLQ $\Rightarrow$ Minimize ΔM_{VLQ}

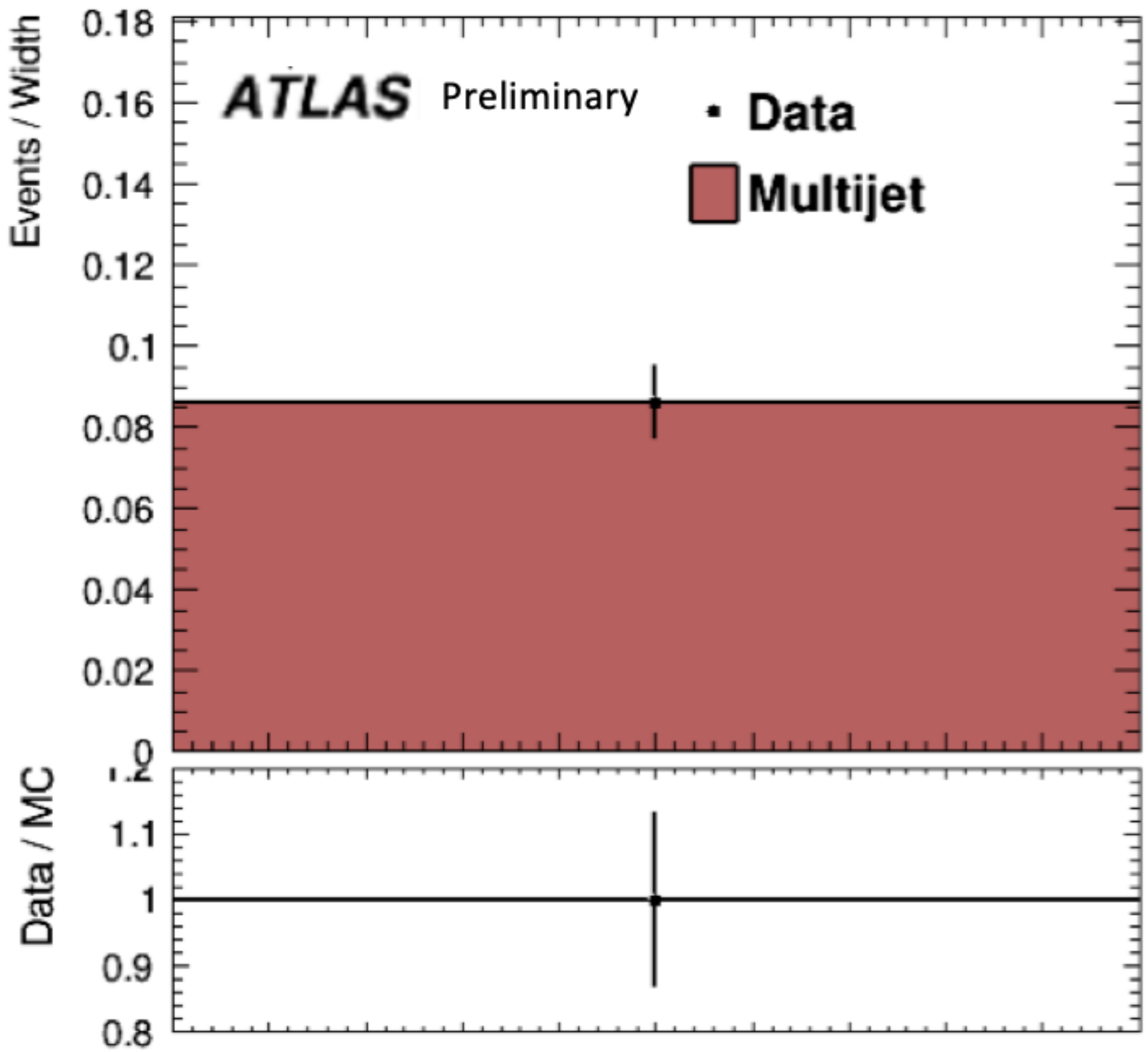


Analysis Strategy

- 1. Reconstruct VLQ candidates
- 2. Correct MC in control regions

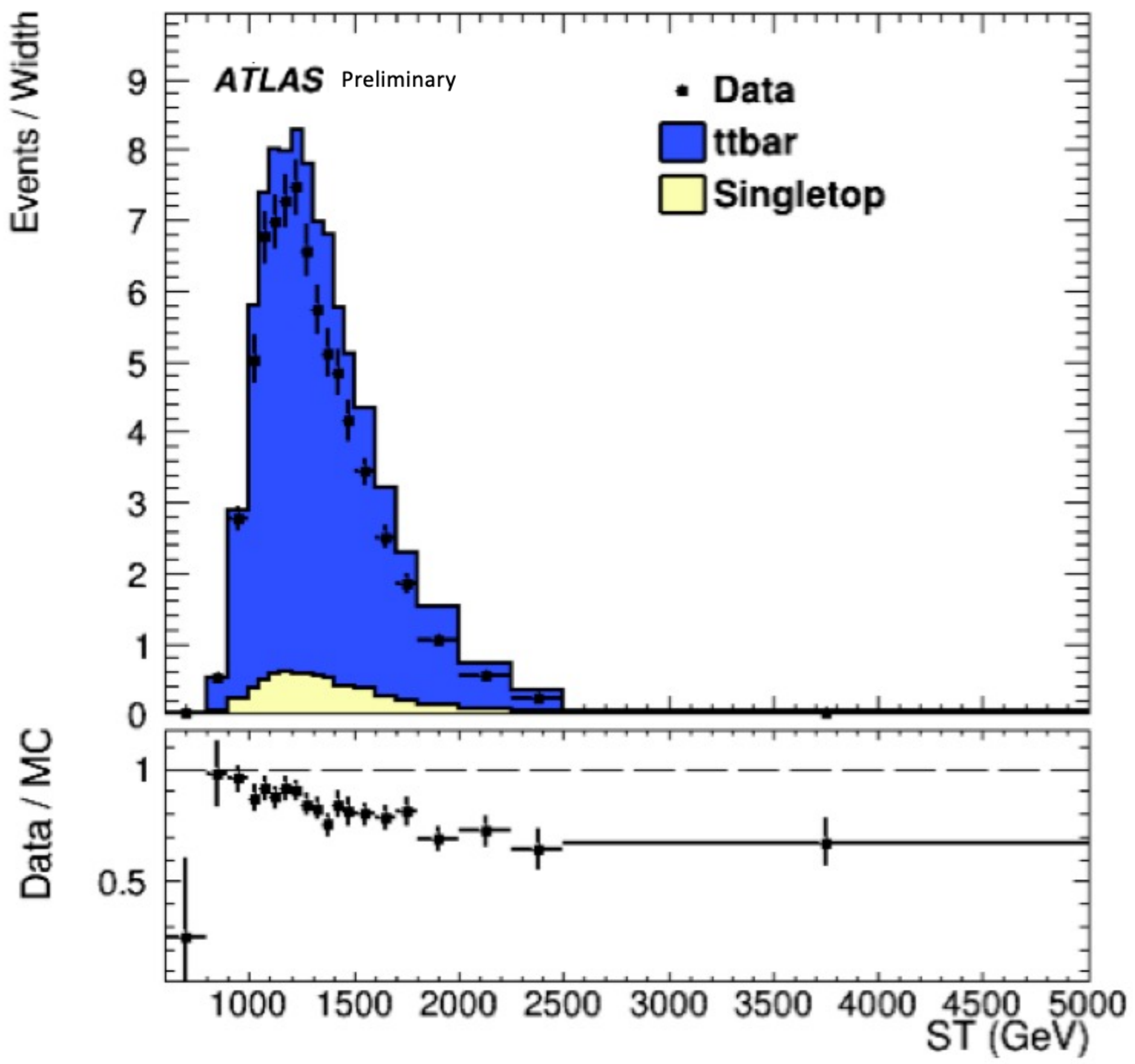
Modelling Checks: Multijet

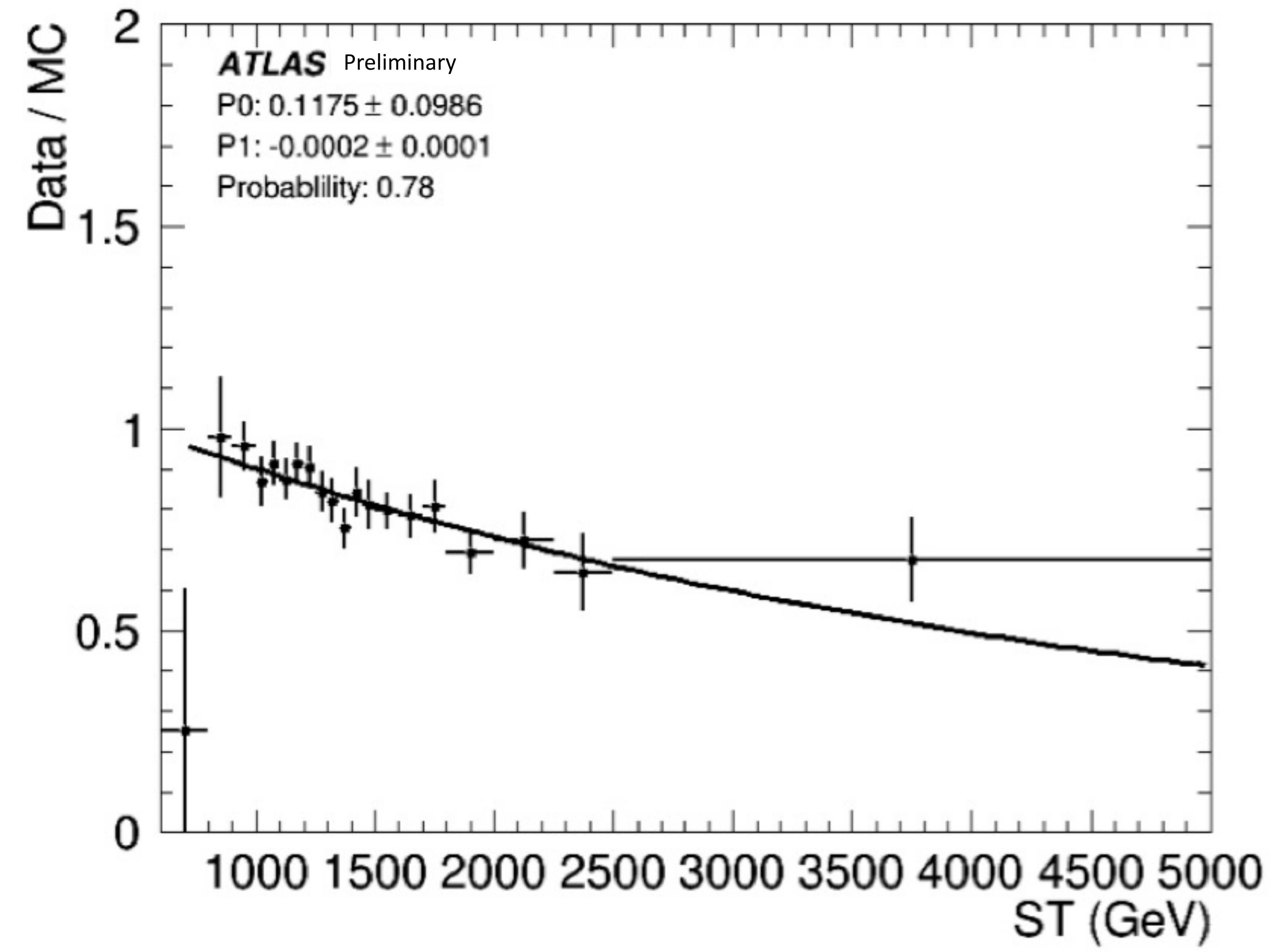




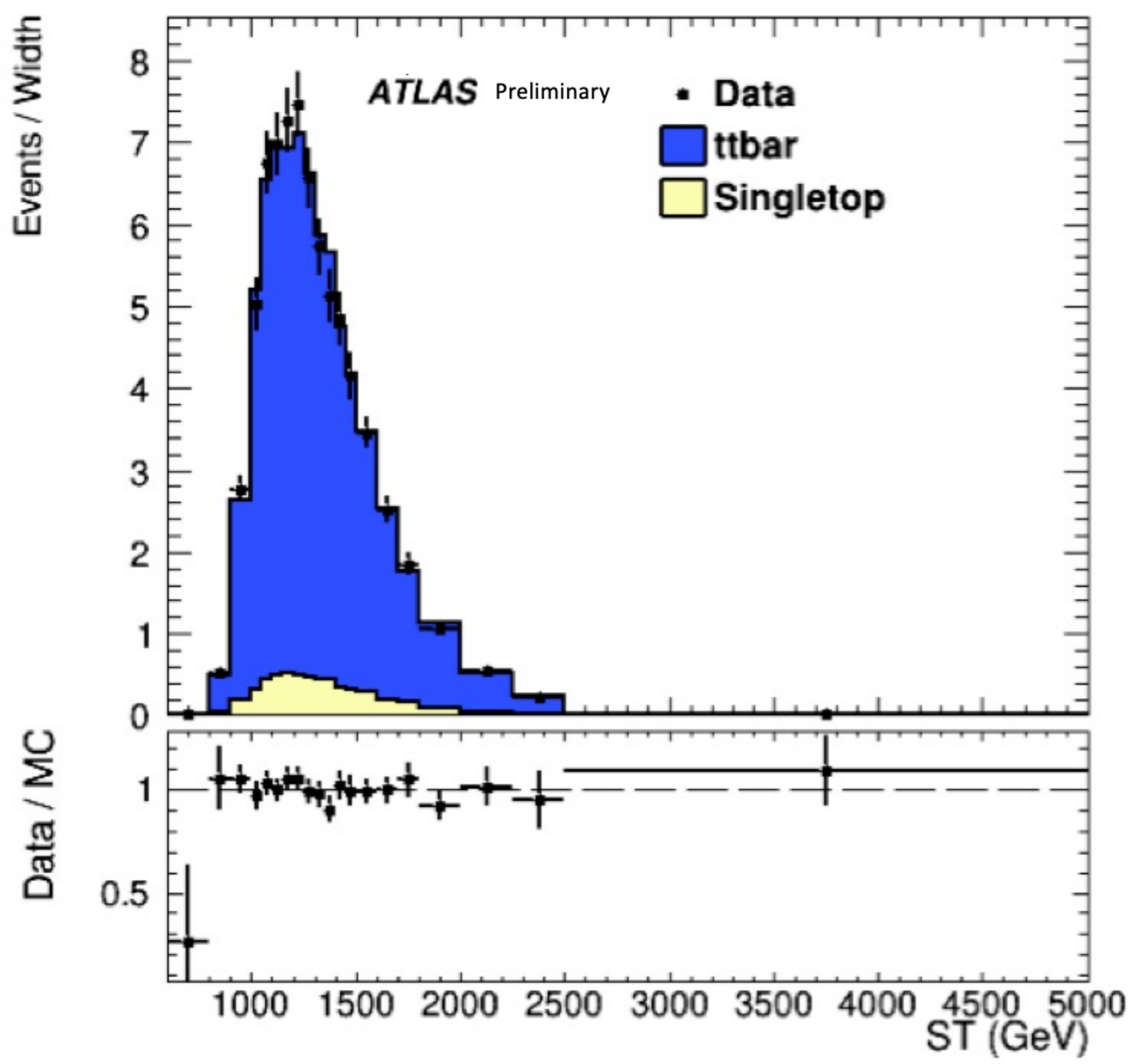
Modelling Checks: $t\bar{t}$

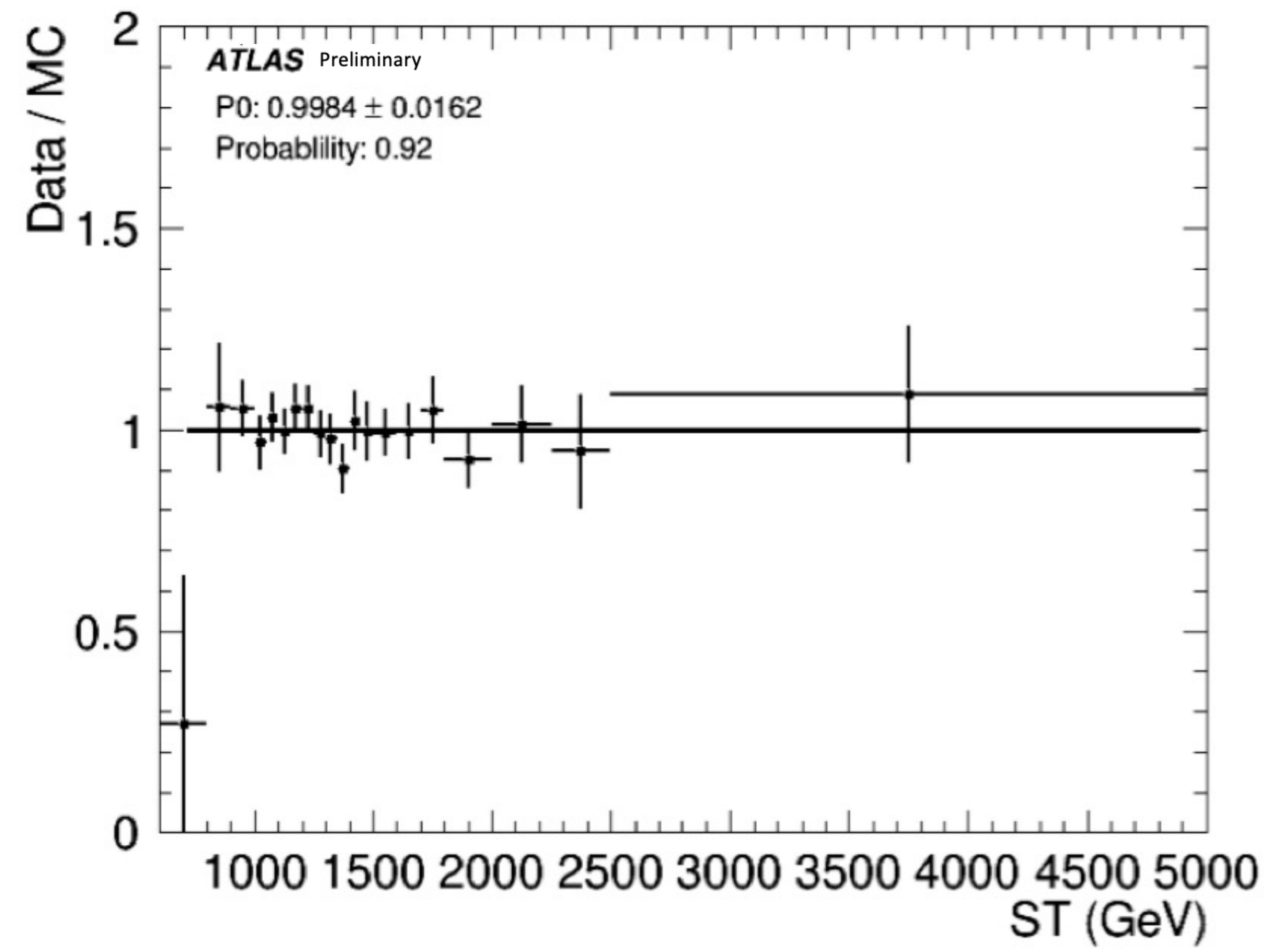
Pre-correction





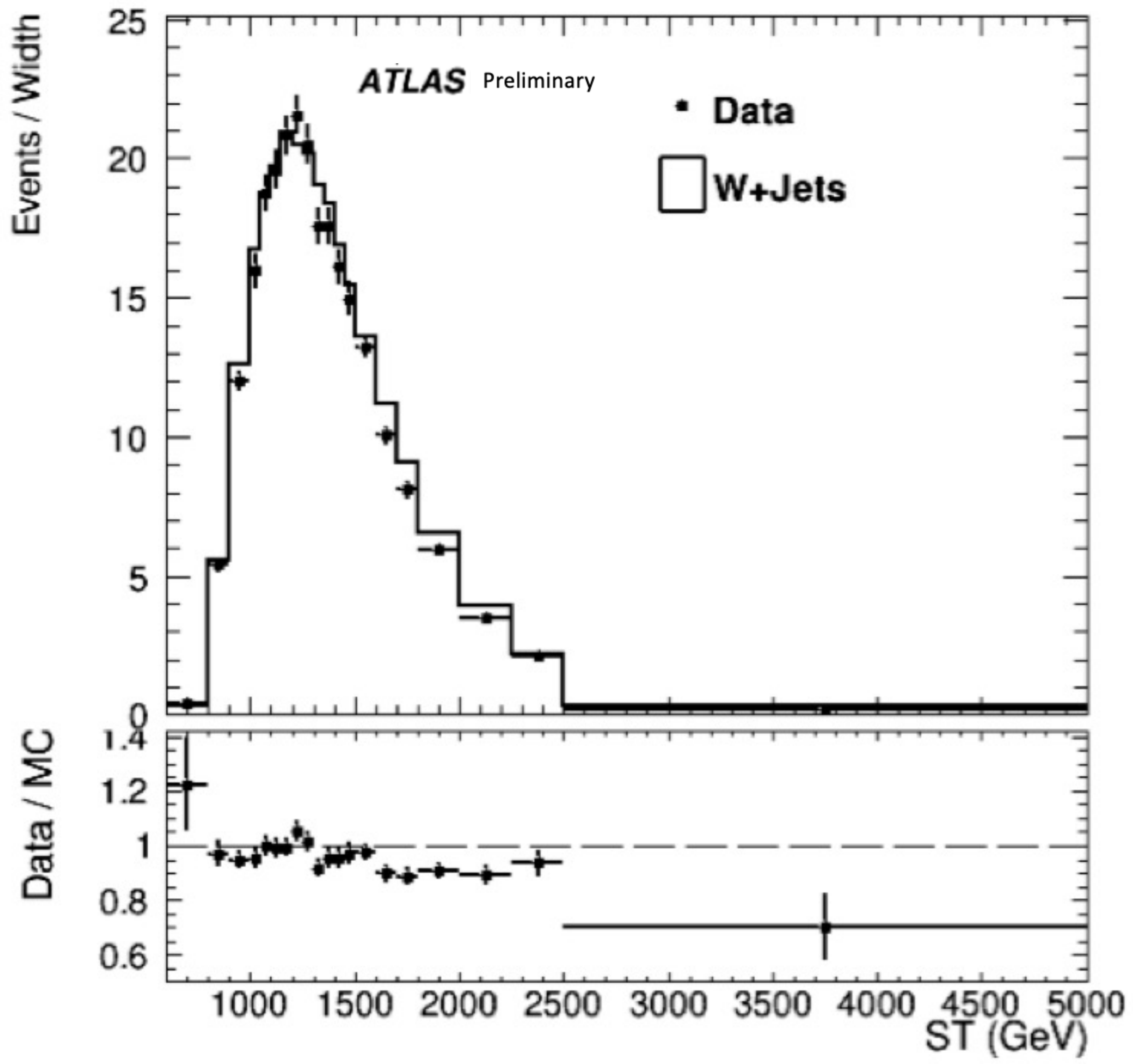
Post-correction

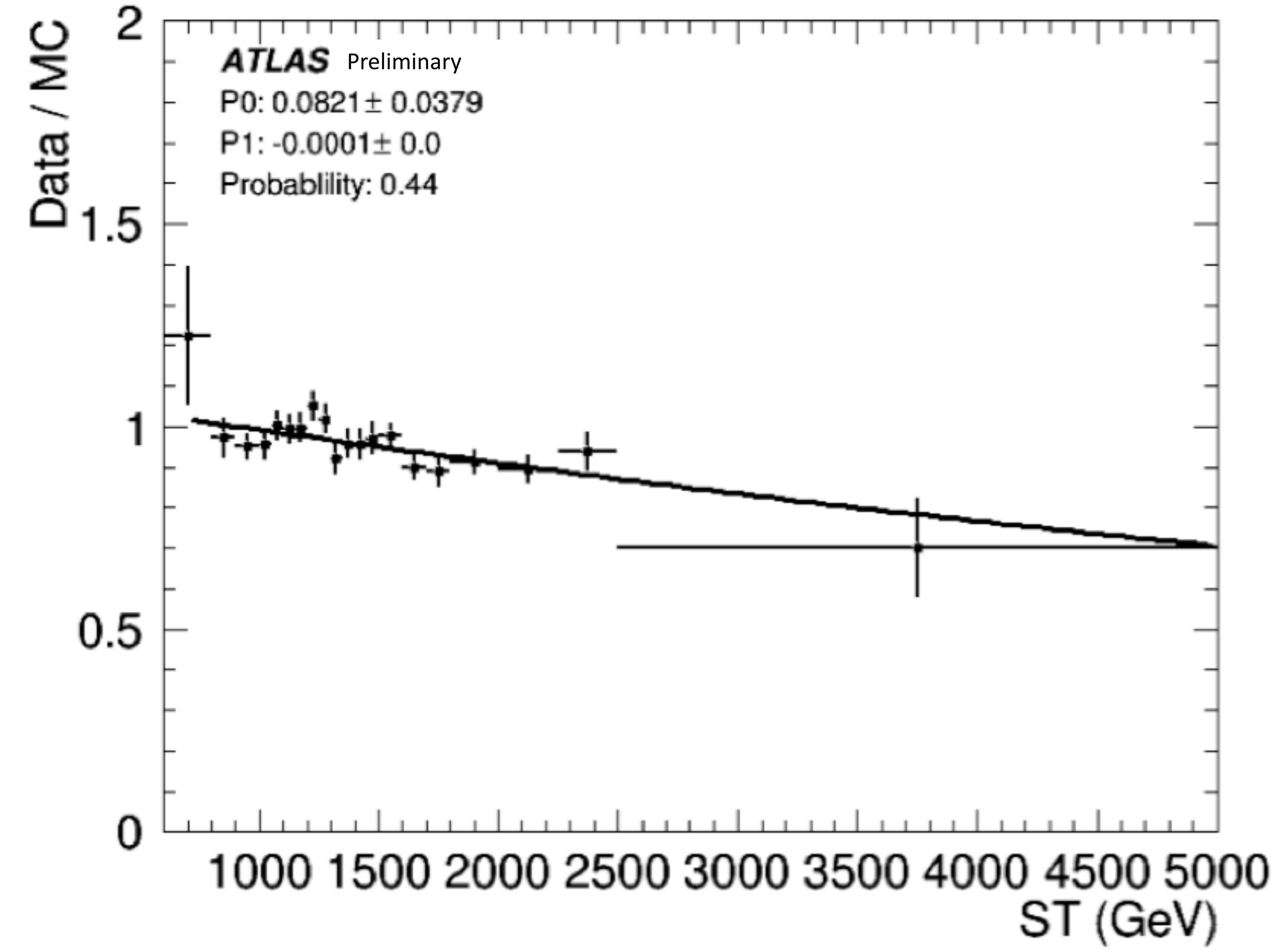




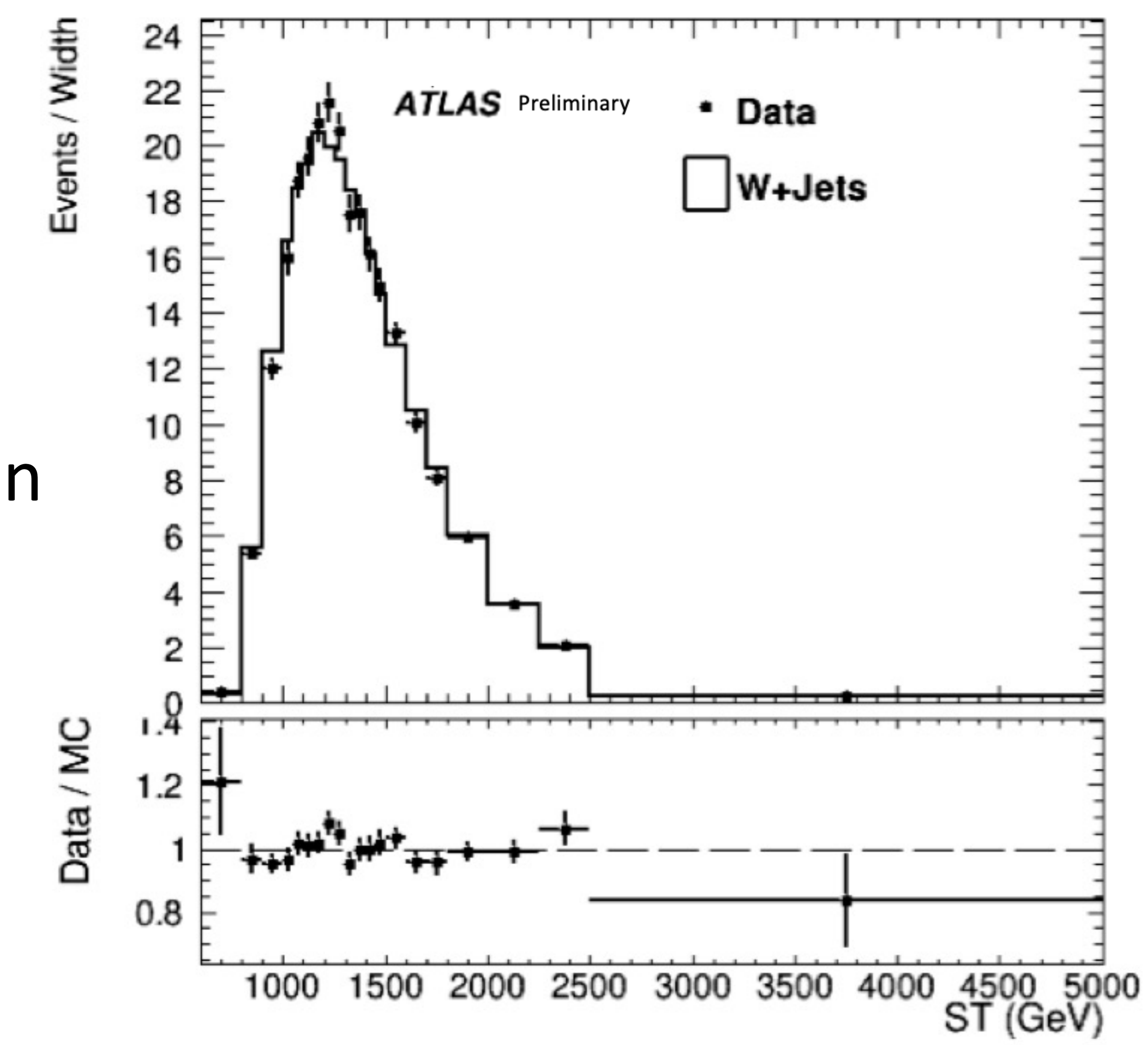
Modelling Checks: W + jets

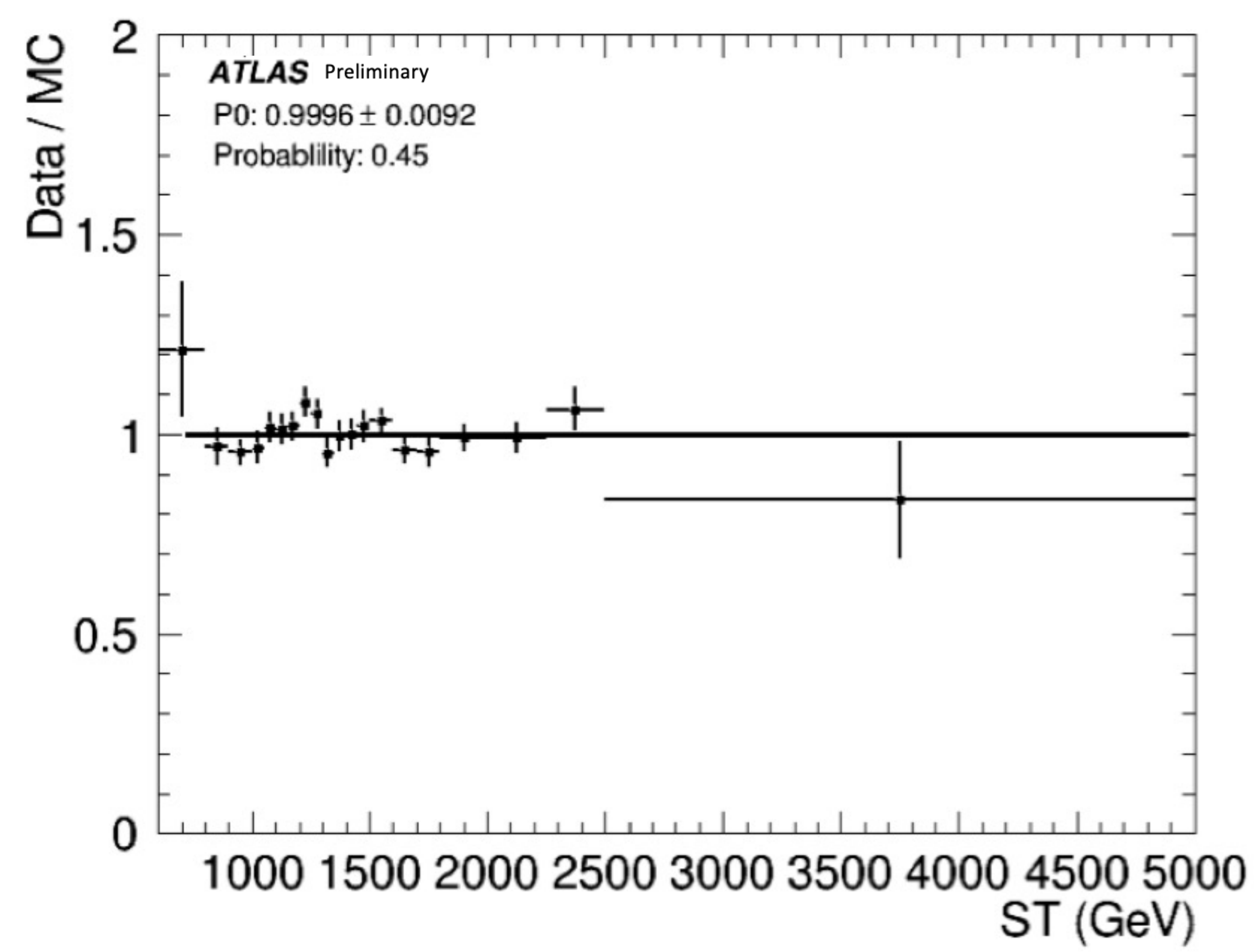
Pre-correction





Post-correction

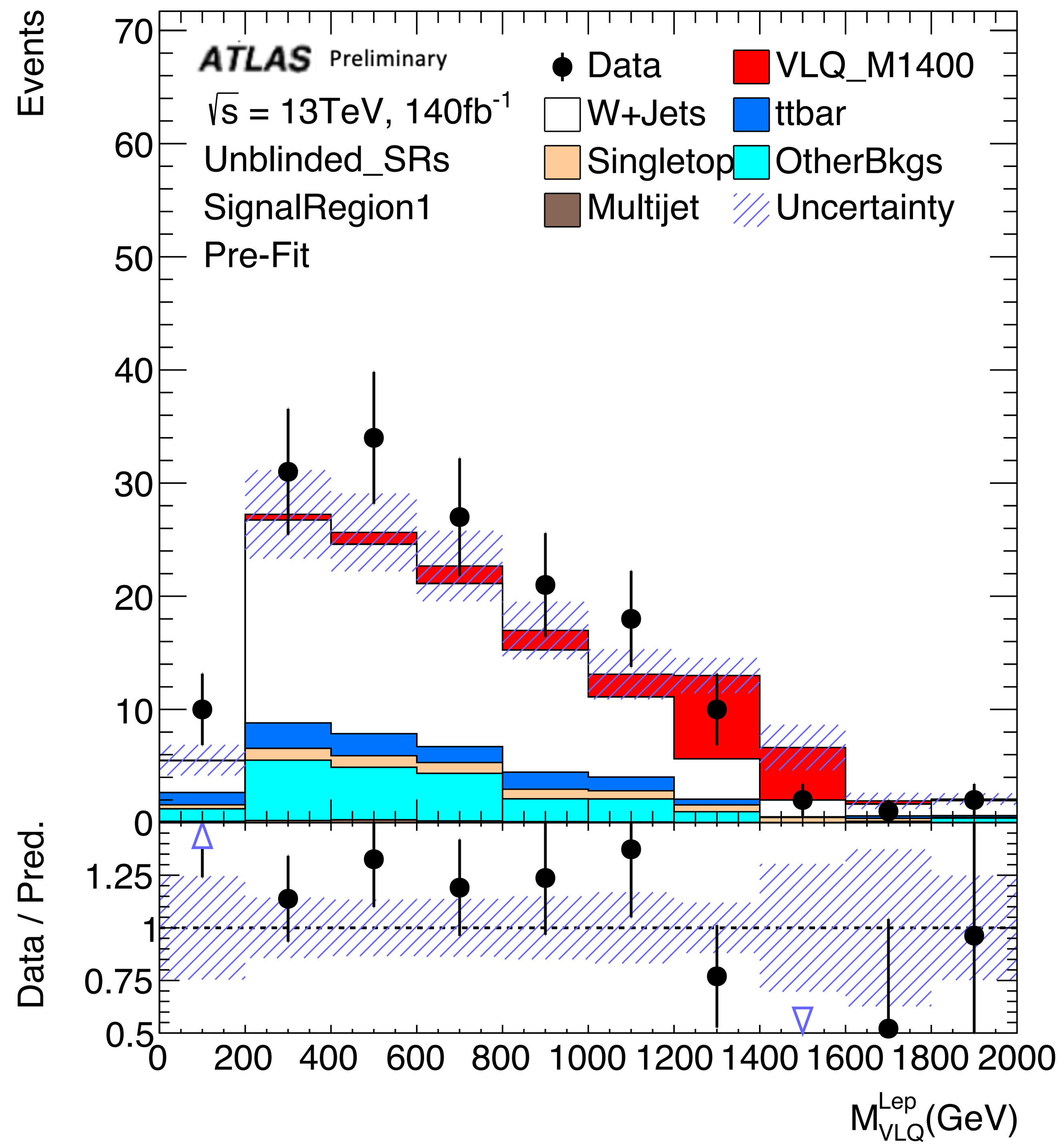


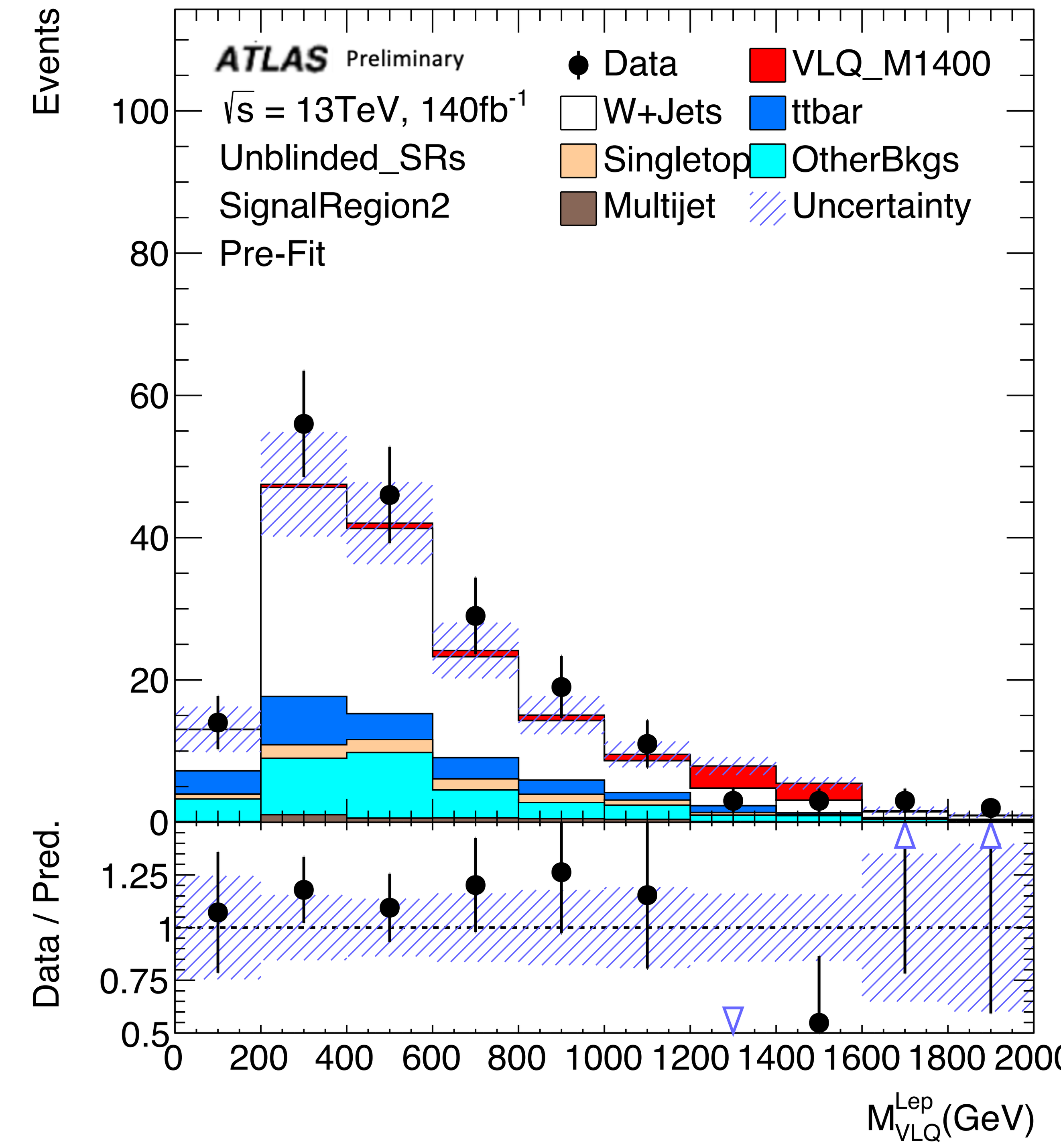


Analysis Strategy

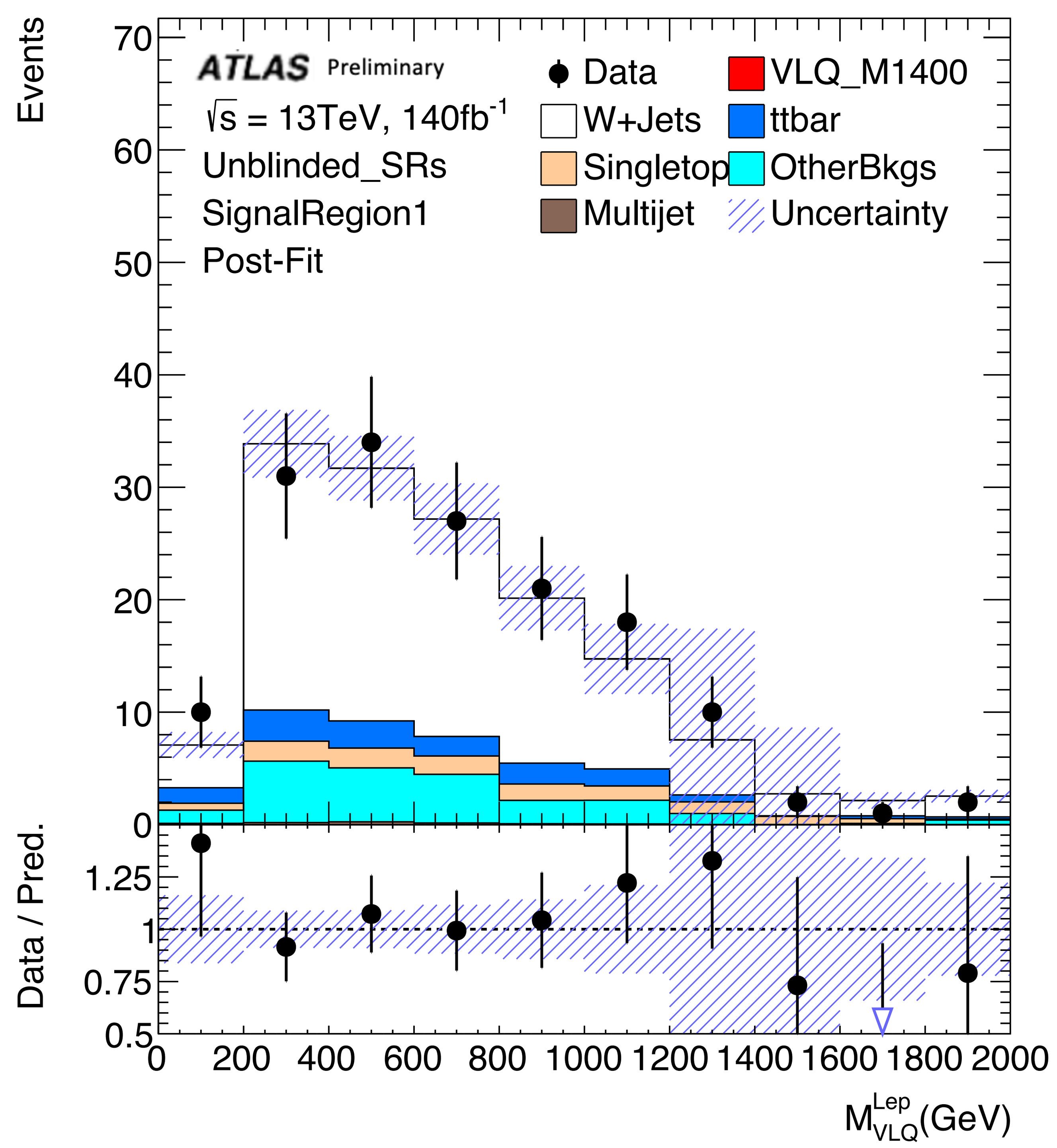
- 1. Reconstruct VLQ candidates
- 2. Correct MC in control regions
- 3. Fit both SRs with respect to mass of leptonically decaying VLQ (M_{VLQ}^{lep}) by performing an S+B fit using TREx-fitter

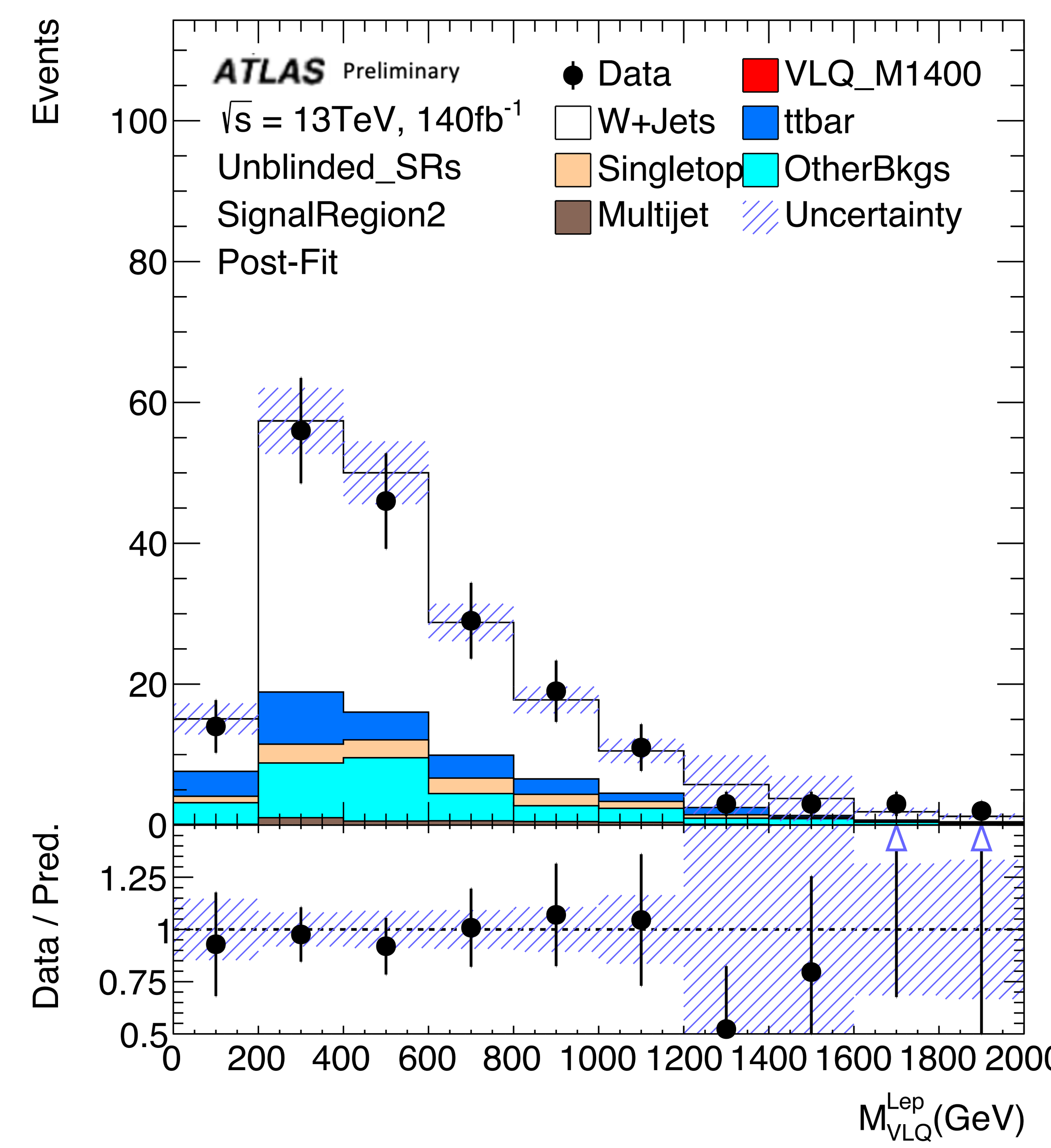
Pre-/Post-fit Plots





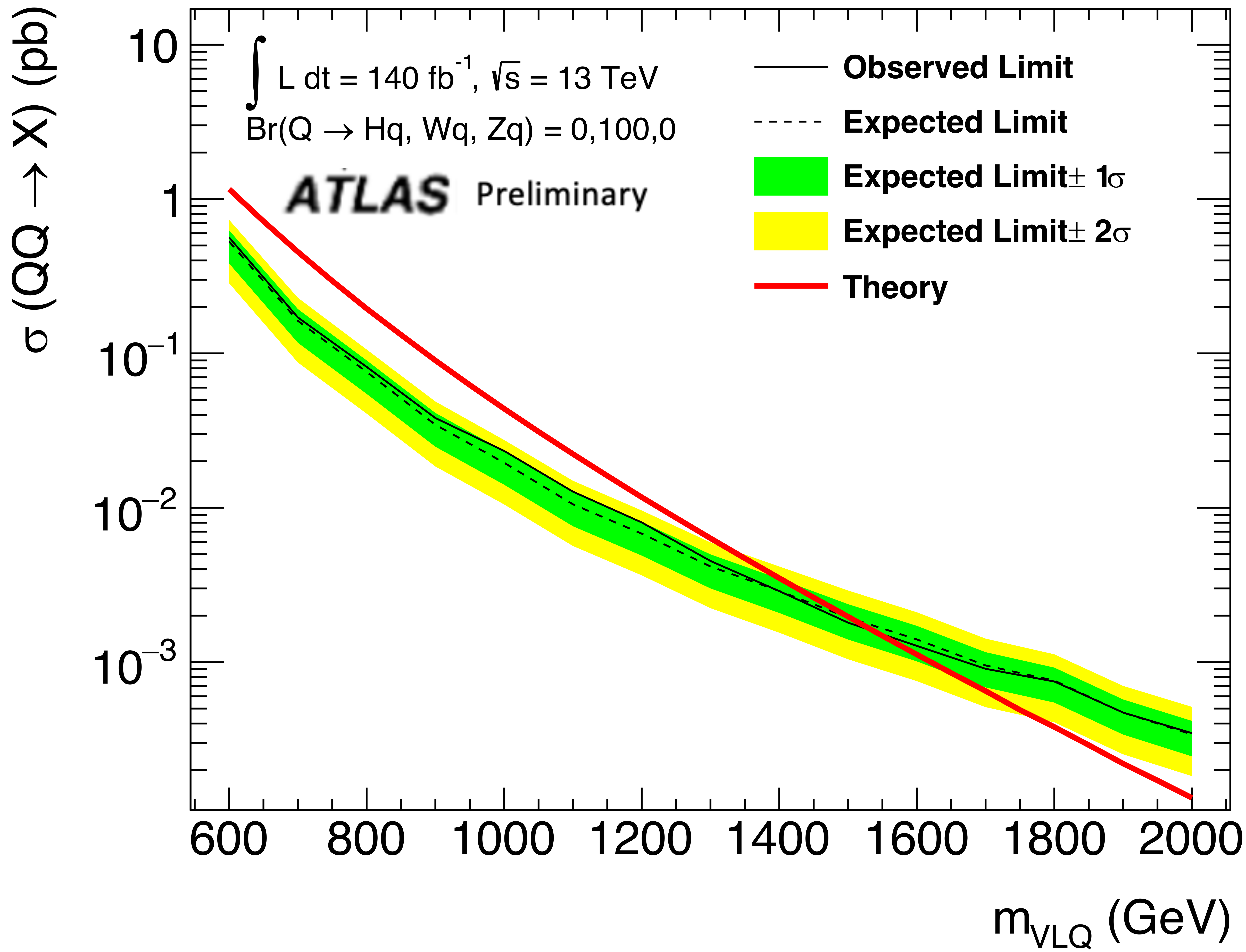
Pre-fit





Post-fit

Limit Plot



∫ L dt = 140 fb^-1, √s = 13 TeV
Br(Q → Hq, Wq, Zq) = 0,100,0
ATLAS Preliminary
Observed Limit
Expected Limit
Expected Limit± 1σ
Expected Limit± 2σ
Theory
σ (QQ → X) (pb)
10
1
10^-1
10^-2
10^-3
600
800
1000
1200
1400
1600
1800
2000
m_VLQ (GeV)

Conclusions

- The analysis more than doubles the limit on the mass of the VLQ which decays to light quarks from the previous Run 1 result of ~700 GeV to ~1525 GeV

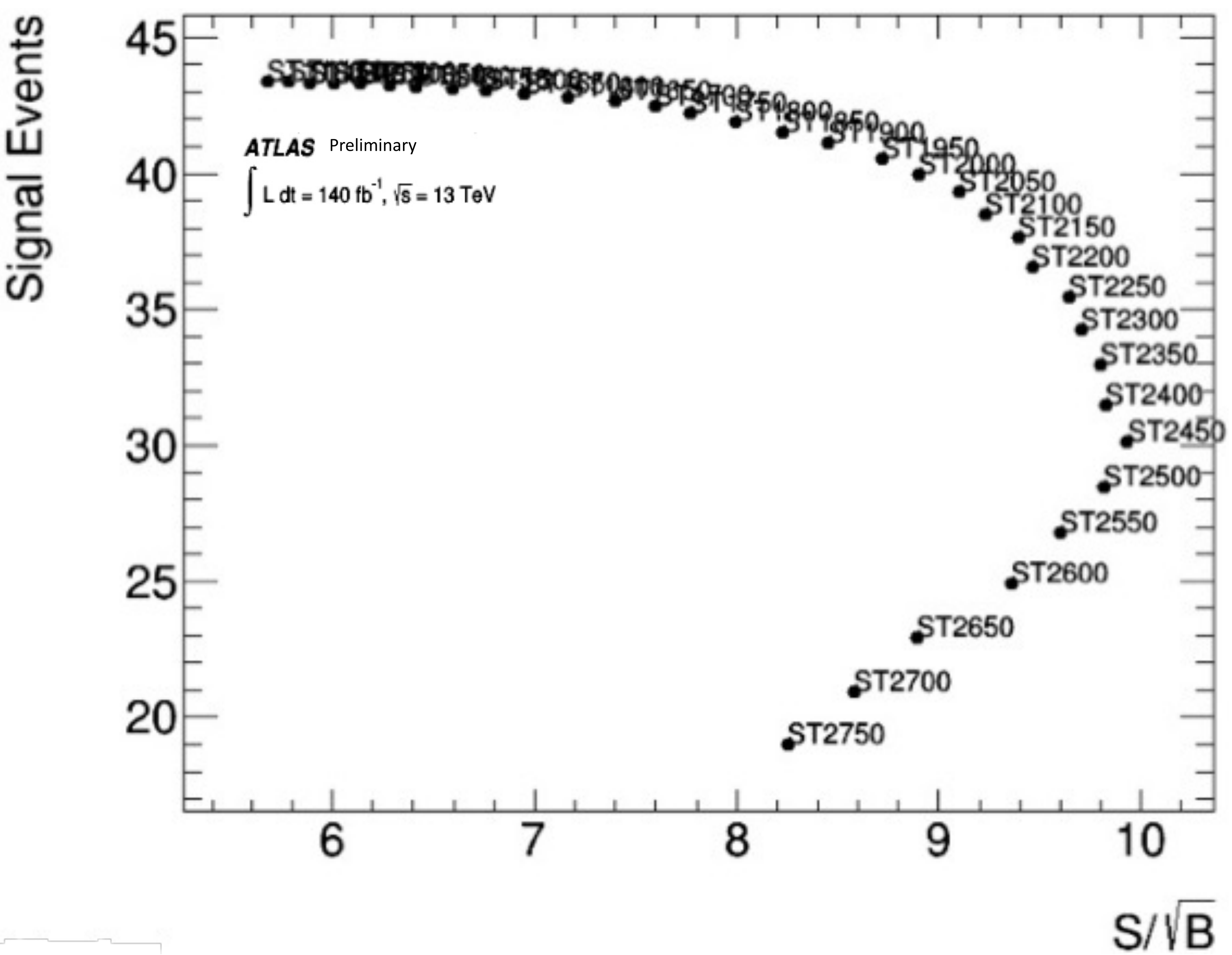
Backups

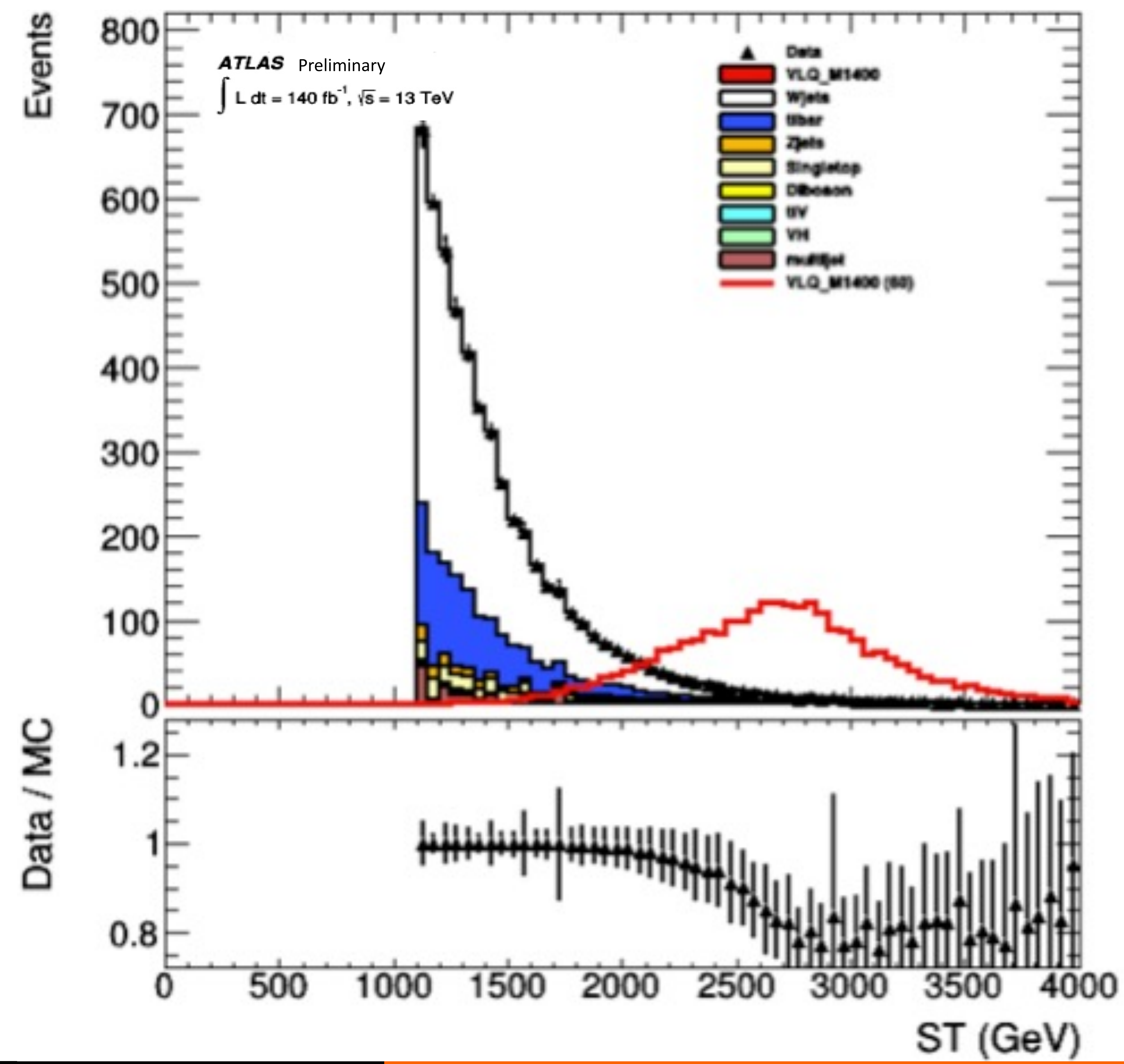
Preselection Cuts

- $N_{large-R\ jets} \geq 1$
- $N_{OR\ small-R\ jets} \geq 2$
- $p_T^{small-R\ jet} \geq 200\ \text{GeV}$
- $p_T^{\ell} \geq 60\ \text{GeV}$
- $\text{MET}\ \geq 250\ \text{GeV}$

Signal Region 1(2) Cuts

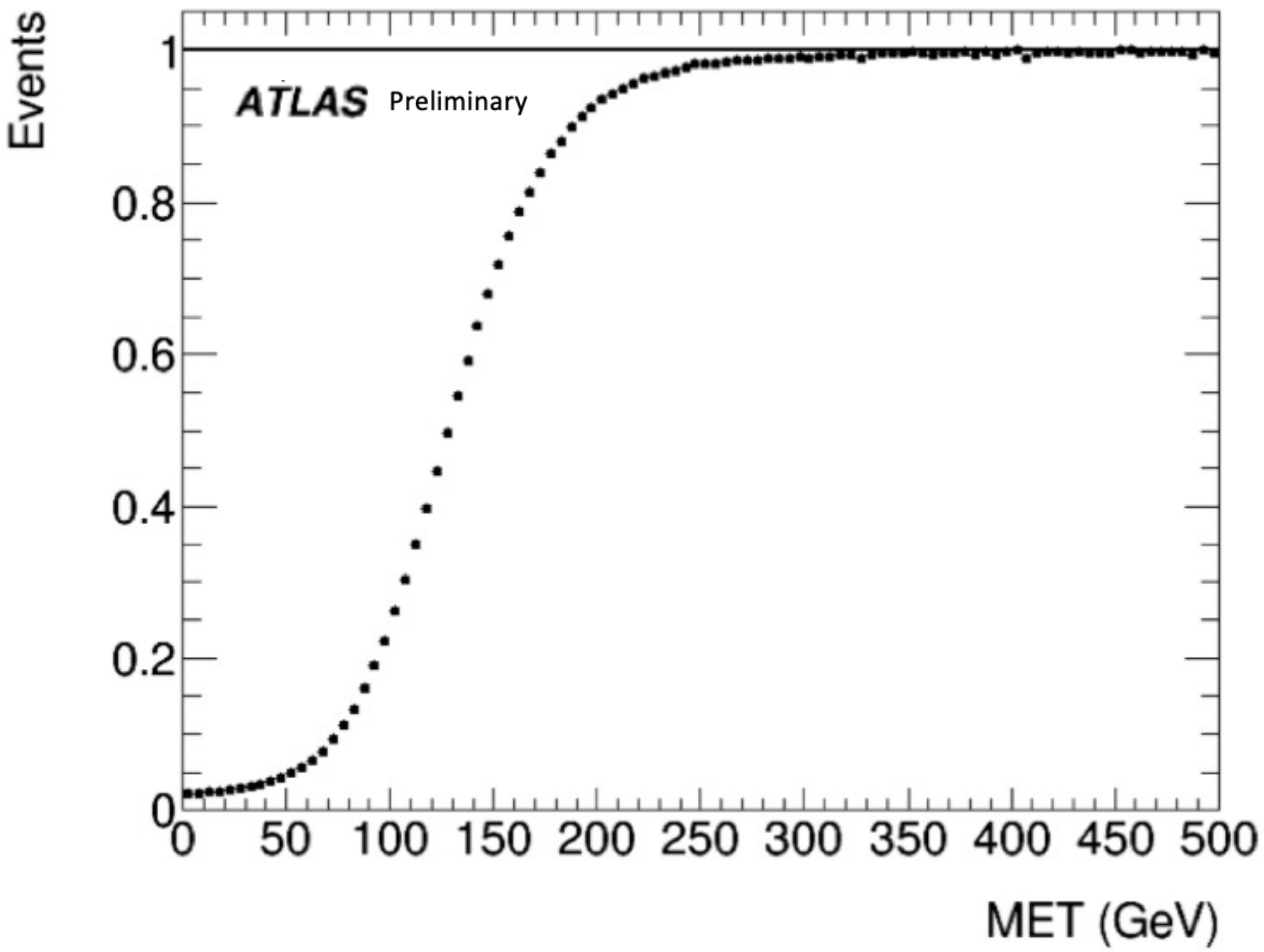
- N_{b-tag} (DL1r 70%) $= 0$
- N_{W-tag} (80%) ≥ 1
- $\Delta\phi(\text{lep, MET}) \leq 0.5$
- $\Delta R(W_{lep}, W_{had}) \geq 0.8$
- $S_T \geq 2000$ GeV
- $\Delta\phi(\text{jet}_0, \text{MET}) < 2.75 (\geq 2.75)$
  - Difference between lower and higher multijet content

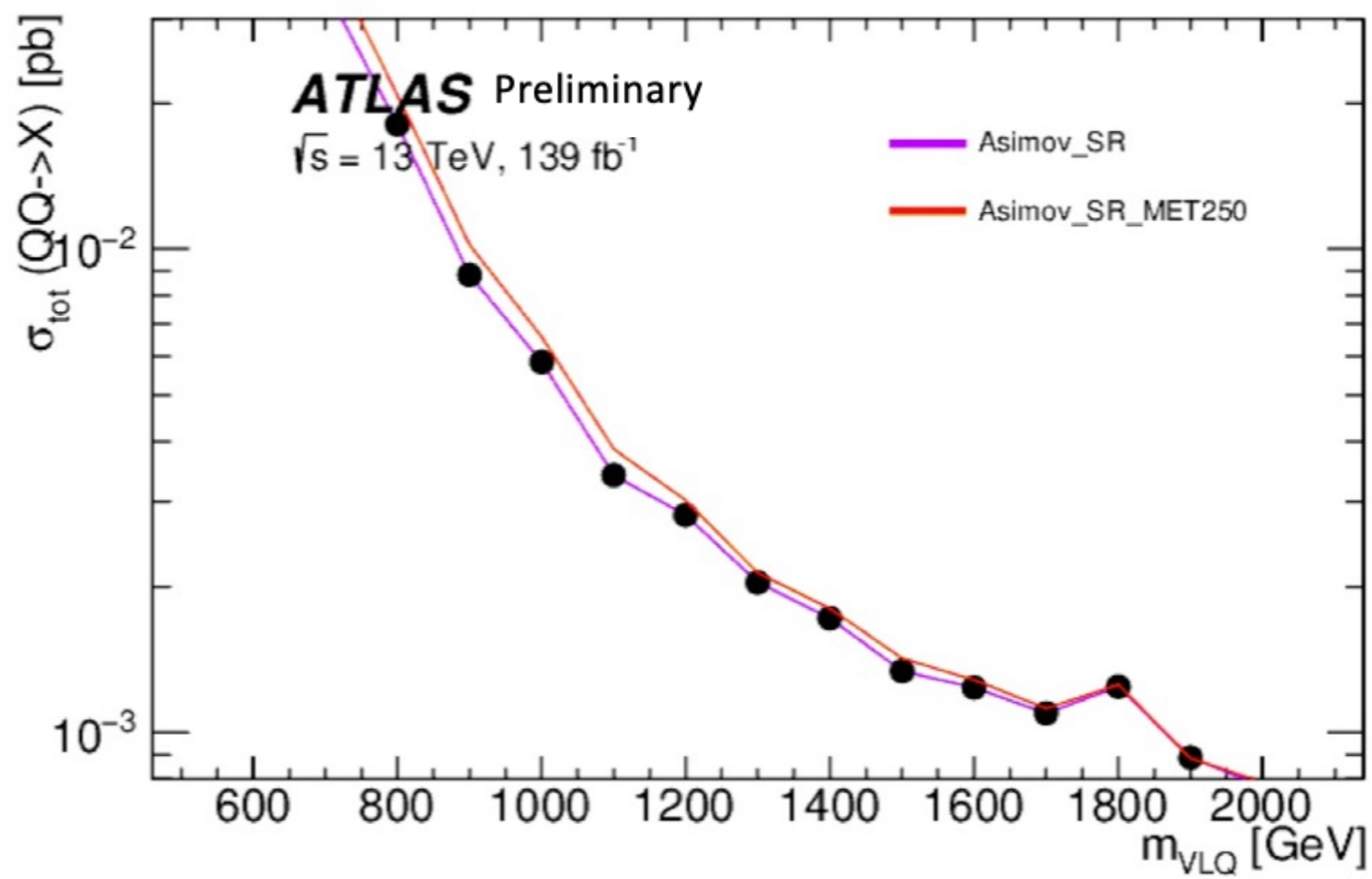




MET Trigger Studies

- Study displayed that MET trigger is fully efficient for $\mathrm{MET} \geq 250\ \mathrm{GeV}$
  - Change in sensitivity is negligible when including trigger vs applying cut



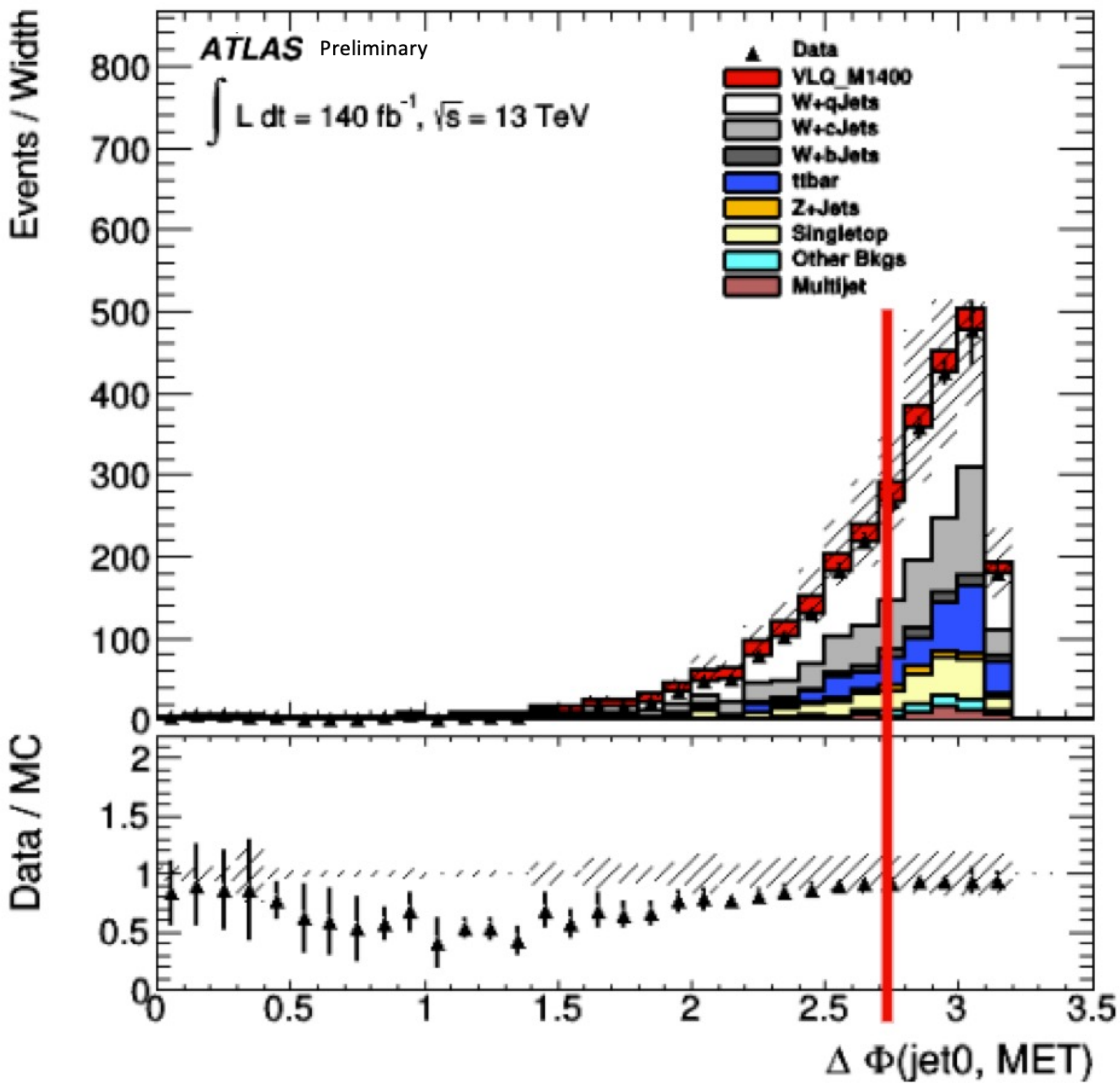


Background Modelling Procedure

- Multijet has normalization corrected
- W + jets and $t\bar{t}$ (and single top) are fit using exponential + offset $P_0 + e^{P_1 x}$
- Correction = $\frac{\text{data}-\text{other MC}}{\text{MC to correct}}$

Step	MC being Corrected	Other Corrections Used
1	Multijet	-
2	$t\bar{t}$	(1)
3	W + jets	(1,2)
4	Multijet	(2, 3)
5	$t\bar{t}$	(3, 4)
6	W + jets	(4, 5)

Signal Region Split

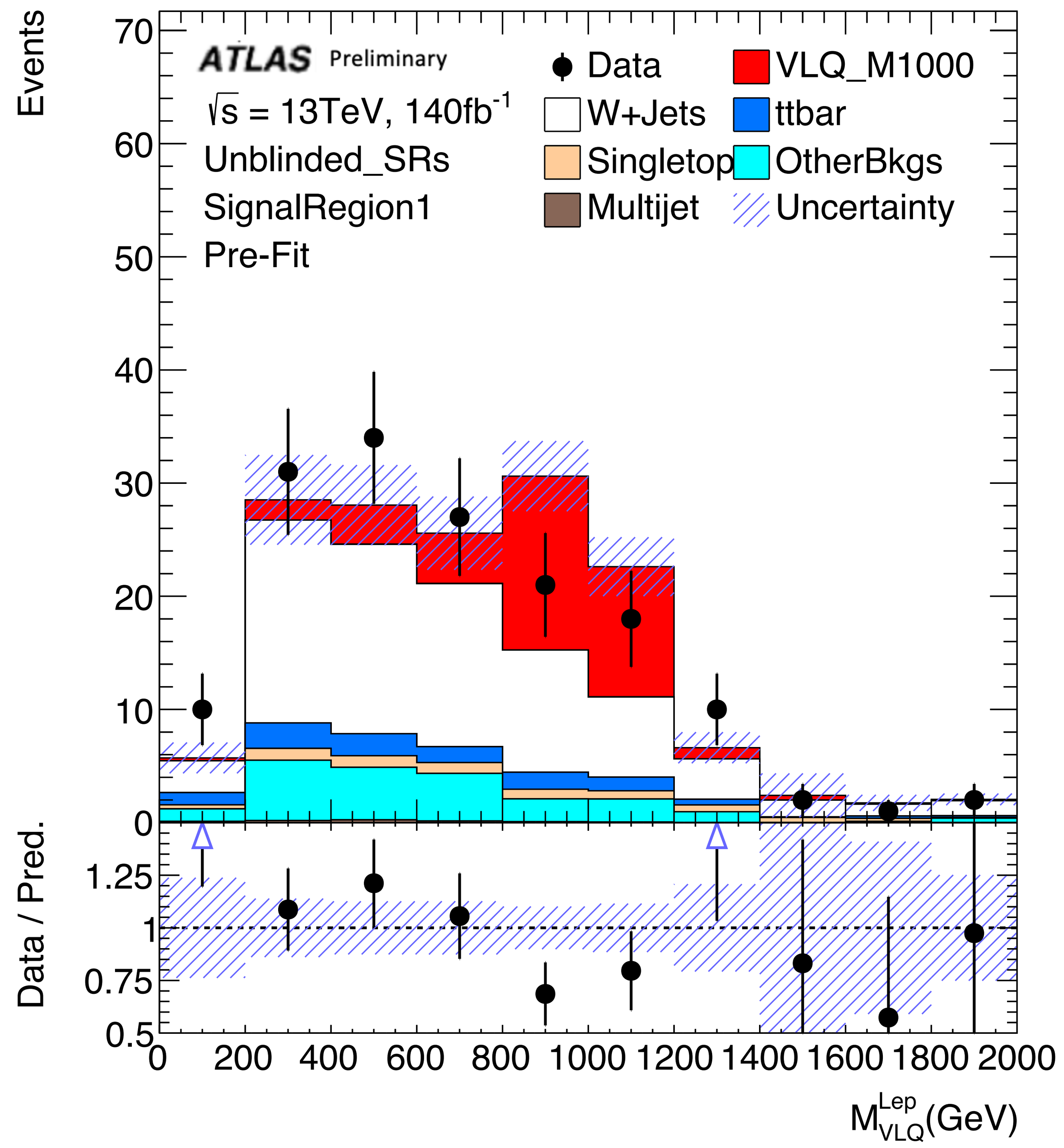


Singlet Model

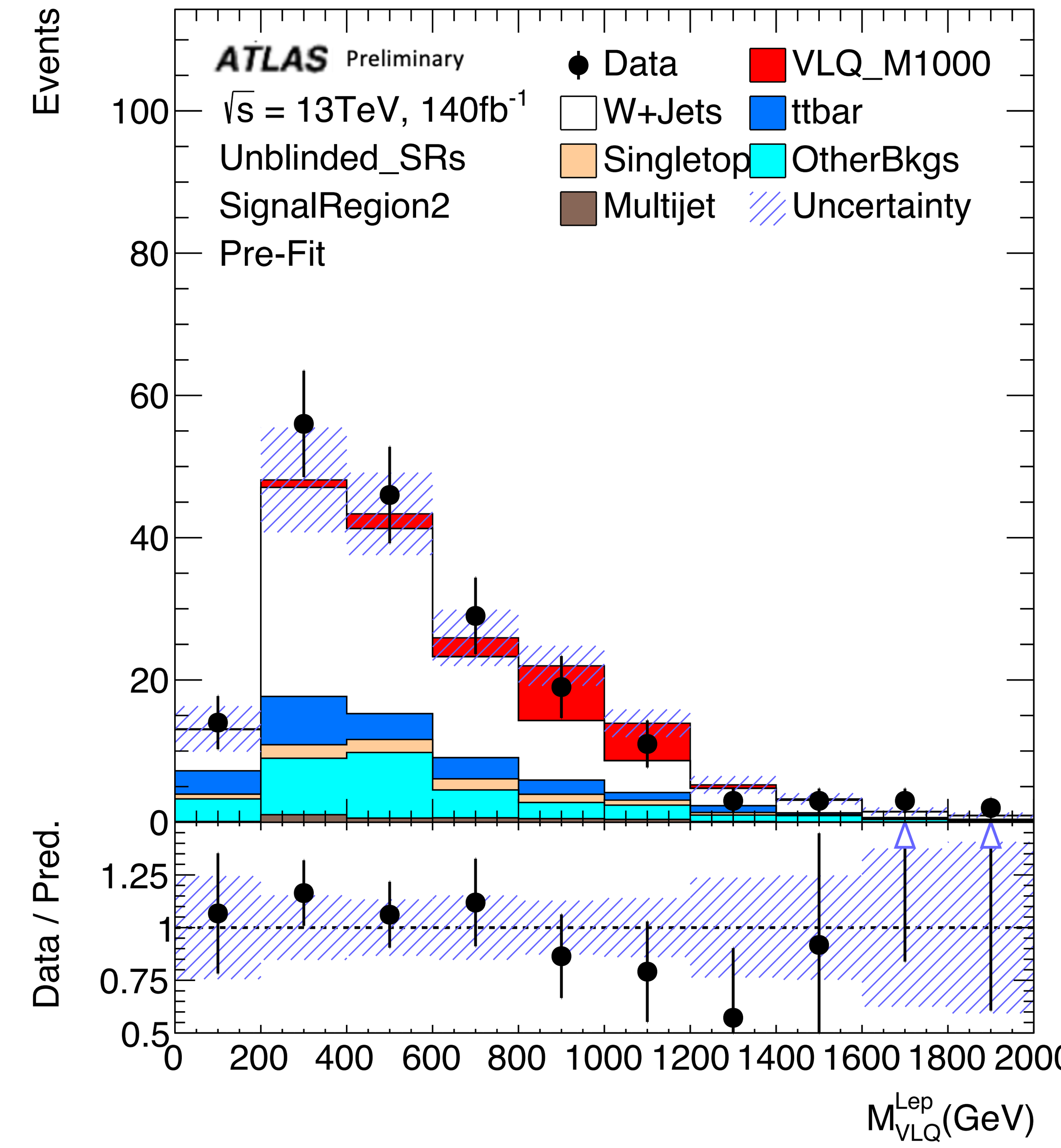
- Analysis is also sensitive other VLQ branching ratios
- Evaluate results for the Singlet model when

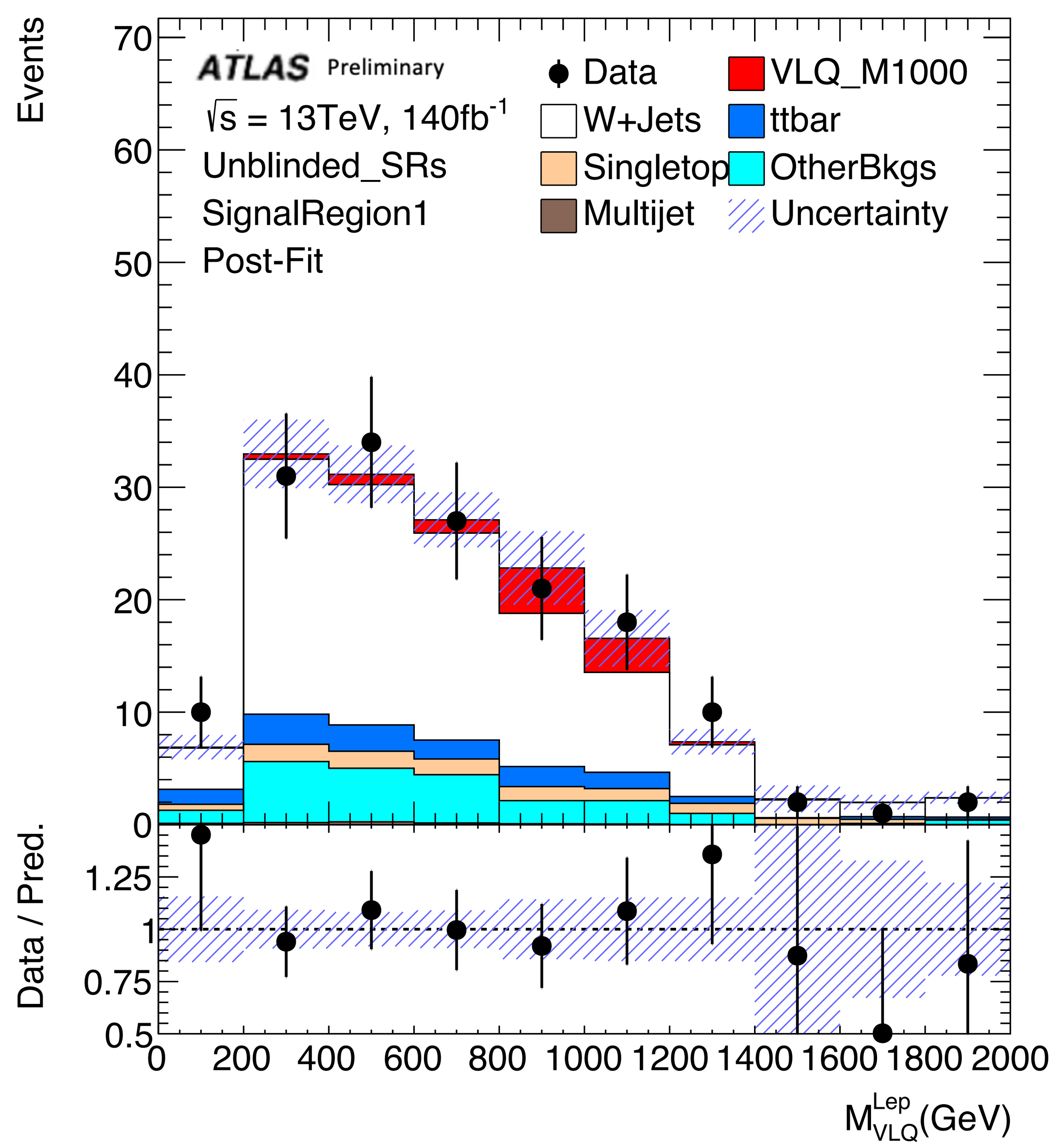
$$\mathcal{B}(Q \to Hq){:}\,\mathcal{B}(Q \to Wq){:}\,\mathcal{B}(Q \to Zq) = 1{:}\,2{:}\,1$$

Singlet Model Pre-/Post-fit Plots

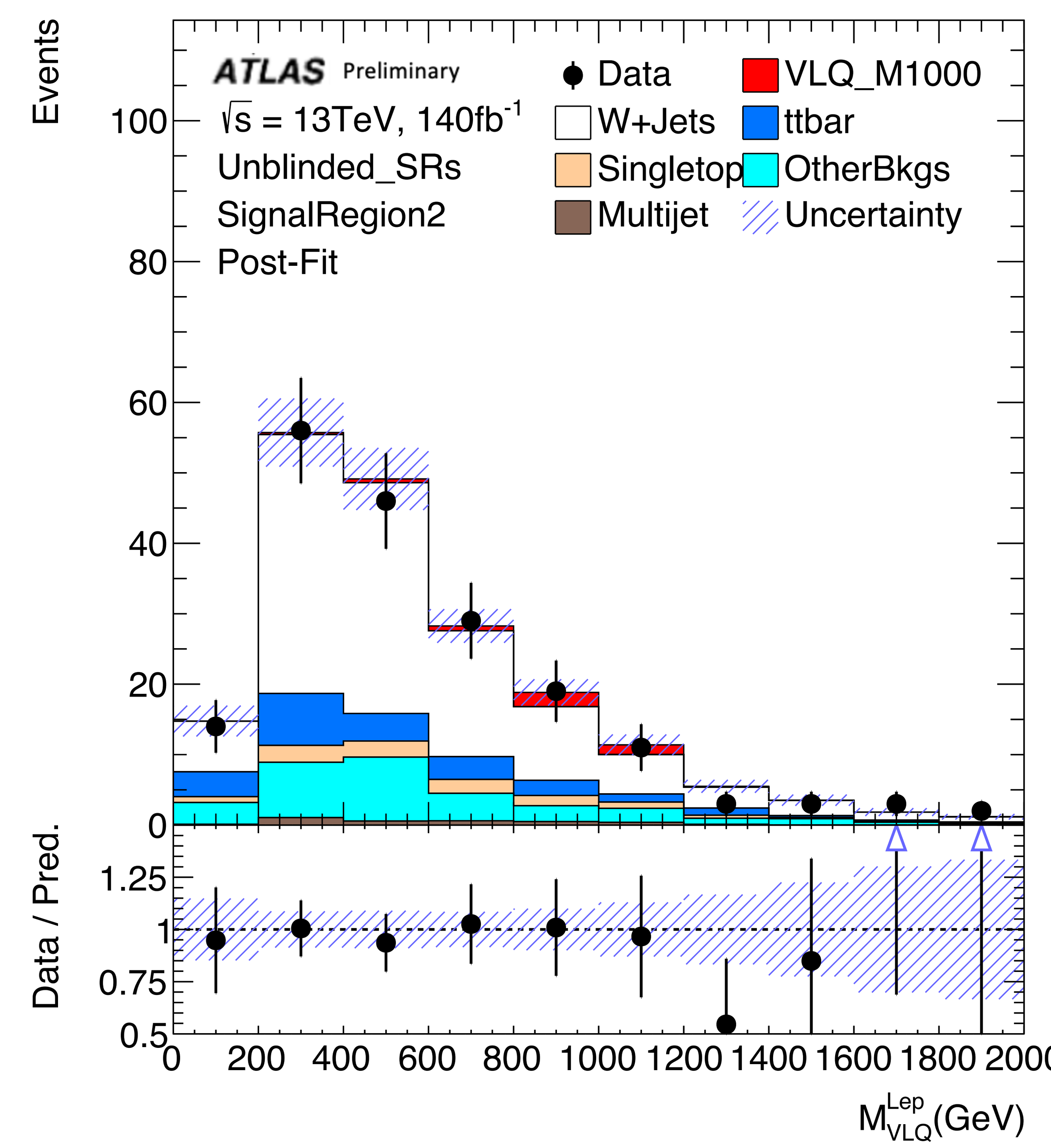


Pre-fit





Post-fit



Singlet Model Limit Plot